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## **Economy and Finance in Smart-Cities**

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## Economy and Finance in Smart-Cities

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### Message from the Guest Editors

*Dear Colleagues,*

*Smart city is spreading very quickly around the world. Important researches have already been conducted in the use of digital technology for smart city transformation. However, a successful smart city transformation requires a deep investigation of issues related to the economy and finance of smart cities, such as the economic model, finance mechanisms, economic return of the investment, integration of environmental and social benefits in the economic return and the private and public partnership. In addition, the smart city concept opens large perspectives for innovation in the field of smart finance and smart economy.*

*The objective of this Special Issue is to publish original papers concerning economics and financing in smart cities with a special interest for feed-back from smart city projects or from related issues such as smart buildings, smart water, smart energy and smart transport. This issue is also interested by innovative concepts and frameworks in the field of Smart Finance and Smart Economy.*

*Prof. Dr. Isam SHAHROUR*

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Perspective

# Disruptive Technologies in Smart Cities: A Survey on Current Trends and Challenges

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**Abstract:** This paper aims to explore the most important disruptive technologies in the development of the smart city. Every smart city is a dynamic and complex system that attracts an increasing number of people in search of the benefits of urbanisation. According to the United Nations, 68% of the world population will be living in cities by 2050. This creates challenges related to limited resources and infrastructure (energy, water, transportation system, etc.). To solve these problems, new and emerging technologies are created. Internet of Things, big data, blockchain, artificial intelligence, data analytics, and machine and cognitive learning are just a few examples. They generate changes in key sectors such as health, energy, transportation, education, public safety, etc. Based on a comprehensive literature review, we identified the main disruptive technologies in smart cities. Applications that integrate these technologies help cities to be smarter and offer better living conditions and easier access to products and services for residents. Disruptive technologies are generally considered key drivers in smart city progress. This paper presents these disruptive technologies, their applications in smart cities, the most important challenges and critics.

**Keywords:** smart city; disruptive technologies; Internet of Things; artificial intelligence; blockchain

## 1. Introduction

The continuous growth of the population in urban areas has led to new challenges. The availability of resources (physical infrastructure), the quality of knowledge communication, and human and social capital (social infrastructure) are considered some of the most important [1]. Access to education, healthcare, transport, justice, social services, utilities, etc., must be available for a population that has grown from 33.6% in 1960 to 55.7% in 2019 [2] and which—according to the estimation of the World Health Organisation—is expected to increase by 1.63% per year between 2020 and 2025, and by 1.44% per year between 2025 and 2030 [3]. To ensure the sustainability of future megacities, an important role is played by how data are gathered, stored, and accessed. Both city authorities and information and communication technology (ICT) companies are responsible for finding the best methods and technologies. Currently, data management systems that integrate the Internet of Things (IoT), big data, and cloud computing are improving certain operations, such as traffic control, sustainable resource management, quality of life, and infrastructure [4]. The smart cities concept includes a wide variety of applications from different fields. Lim et al. [5] identify four groups of technological factors in smart cities, namely, the “4Cs”: Connection between things and people, Collection of data for context awareness, Computation in the cloud, and Communication by wireless means. These factors require a variety of technologies characterised by an accelerated and continuous dynamic. The massive amount of information, the speed of updating, and the increasing number of users are some of the elements that determine the emergence of disruptive innovations, mainly in the ICT area. They are rapidly assimilated by consumers. The disruptive technologies are defined as “innovative solutions that require fewer resources and can grow exponentially, very often, shaking up the economy and



structure of the related businesses” [6]. They also bring some challenges. The controlled transition of the labour market due to automation, winning the war on talent between metropolitan areas, social cohesion, inclusiveness, solidarity, secure digital environment, privacy, and resilience are some of the most significant [7]. Ullah et al. [8] identify Big9 disruptive technologies clustered in three domains: data mining—big data and artificial intelligence (AI); networking—cloud, software as a service, IoT and drones; and data collection technologies—3D scanning, wearable tech, virtual and augmented realities. Investment in these technologies has the potential to accelerate the evolution of the smart city [9]. This is conditioned by the coordination between the three pillars of a city: the industry (production), citizen (consumption), and government (circulation) [10].

The technological evolution depends on the economic context—smart economy in smart cities. This concept is used in various contexts regarding smart urban design and development, economic development, strategic planning, advertisement of the cities, and branding [11]. Without a universally accepted definition, all proposals mix the following terms in various variants: ‘innovation and creativity’, ‘technology’, ‘renewable resources’, ‘environmental protection’, ‘social responsibility’, ‘new jobs and new business’, ‘labour market flexibility’, ‘competitiveness’, ‘entrepreneurship’, and ‘integration in local and international markets’. All these concepts, integrated into the definition of the smart economy, prove both its complex role in the development of the smart city and the influence of the evolution of all other fields in the development of the smart economy. They are both drivers and consequences. First, the adoption of the disruptive technologies requires considerable financial and human investment. This can be achieved by attracting talent, by infusing public and private investment, and by citizens’ involvement as consumers and suppliers. Citizens are important sources of information for co-creating Internet-based applications in all sectors of the economy [12] and are creators and beneficiaries of technological evolution and economic progress.

This research further explores the opportunities and challenges of four disruptive technologies: IoT, big data, AI, and blockchain for the development of smart cities. Previous research presents the role of disruptive technologies in specific fields of the cities in general or in the particular case of smart cities, such as real estate [8], transportation and mobility [13–15], health [16], smart homes [17], etc. Other research address only one disruptive technology such as AI [18,19], big data [20], blockchain [21,22], or IoT [23]. This paper offers an overview of all these disruptive technologies together with their contribution to the development of smart cities. It is also exemplified how they are used for each of the six specific components of the smart city (smart economy, smart mobility, smart governance, smart people, smart living, and smart environment). The interdependence between these technologies and the critical aspects that must be had in their implementation and use in real life is highlighted.

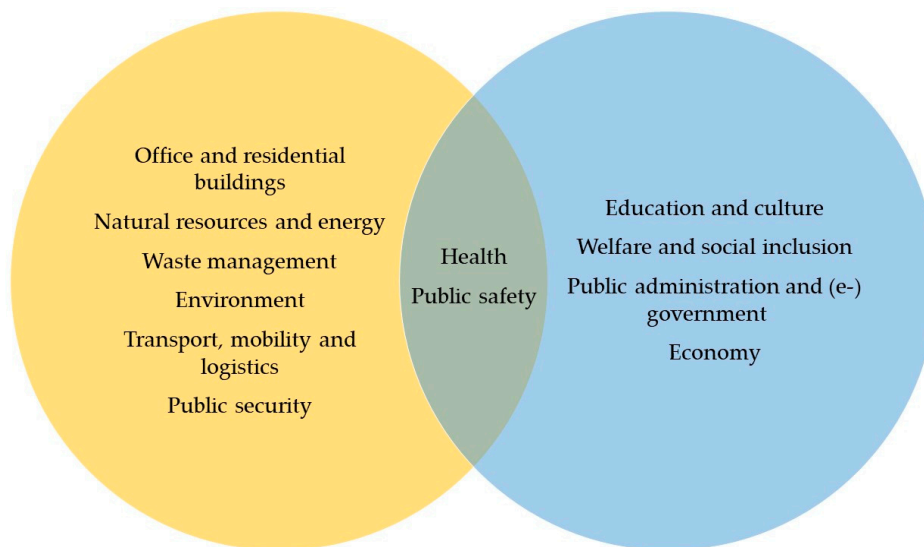
This paper has the following structure: Section 2 presents a background of previous research, Section 3 introduces the materials and methods employed to analyse the disruptive technologies in smart cities, then Section 4 displays the results of our search, while Section 5 discusses their relevance. Finally, Section 6 concludes the paper and suggests potential future research.

## 2. Background

There are various definitions of smart cities, all related in various ways to the evolution of the digital society. However, smart cities are not just about automating routine functions, optimising the use of space, buildings, or traffic management systems. They should provide support for monitoring activity in cities, understanding, and the analysis of economic and social life to increase the efficiency and quality of life and to ensure equity. The smart city also means providing premises that could generate smarter and more accessible ways to interact, especially between citizens and local government or between suppliers of products and services and consumers. According to Batty et al. [24], in smart cities, ICT is “merged with traditional infrastructures, coordinated and integrated using new digital technologies”. Everything becomes part of a system of ultra-connected subsystems that allows real-time access to information, products, and services. The level of integration of these subsystems

is an indicator of the intelligence of cities and allows for the optimisation of the flow of information between subsystems and citizens.

According to Muvuna et al. [25], smart cities have to be redesigned to become more sustainable, integrated, and collaborative. Many projects address specific issues facing the city administration and citizens. They have been developed to solve specific problems related to parking, air pollution, traffic congestion, waste management, tax management, health information management, etc. Chourabi et al. [26] identified eight groups of critical factors in creating a framework for smart cities' development: management and organization, technology, governance, policy context, people and communities, economy, built infrastructure, and natural environment. They are currently the basis for setting priorities on local government agendas. Neirotti et al. [27] divided concerns about smart cities into two major areas (Figure 1).



**Figure 1.** 'Hard' and 'soft' domains of smart cities (author' elaboration after [27]).

Tangible assets or 'hard' domain refer to initiatives on buildings (residential and office), natural resources management, energy management, energy grids, waste management, environment, transport, and logistics, and public security. Intangible assets or 'soft' domain include investment and innovation in education and culture, welfare and social inclusion, public administration and (e-) government, and the economy. Health and public safety are special categories. They are at the interaction between hard and soft domains because it involves both the creation of devices and software, as well as campaigns and practices created to generate social values [27]. All these categories of assets transform the city into a living one that feels and acts due to the connection of billions of sensors, wireless technologies, and software solutions capable of managing a huge volume of various data (big data). This is possible due to the evolution of Big9 disruptive technologies [8]. They underlie the development of applications for entertainment, building management, traffic management, water quality, public safety and services, smart lighting, forest fire detection, wine quality, autonomous vehicles, smart home, and office, etc. The next sections present more information about these technologies and specific areas of use.

According to Batty et al. [24], smart cities are instruments that support the improvement of competitiveness and contribute to a significant increase in the quality of life. Open data, infrastructures, mobile applications, public participation tools, IoT platforms, etc., are designed to ensure that citizens have access to the resources needed. According to Deloitte Consulting Group [7]:

"A city is smart when investments in (i) human and social capital, (ii) traditional infrastructure and (iii) disruptive technologies fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance."

According to a report published by Statista [28], the worldwide spending on the IoT was around USD 646 billion in 2018 and USD 1100 billion in 2023. The most significant increases are estimated in the fields of discrete manufacturing, utilities, transport, and logistics. AI software revenue is also forecast to grow from USD 10.1 billion in 2018 to USD 126.0 billion by 2025 according to a report published by Tractica [29] across 28 industry sectors. Smart projects require specialised staff and create new jobs and opportunities for start-ups. Blockchain has the potential to improve transaction speeds, enhancing security, and reducing costs in the banking sector [30], which would enable real-time accounting [31], and would improve the trustworthiness of financial statements [32]. According to a report published by Statista [33], the spending on blockchain solutions was USD 1.5 billion in 2018 from USD 0.95 in 2017 and is expected to grow to USD 15.9 billion by 2023. They increase the dynamics of transactions and, implicitly, of economic activity as a whole. AI and IoT change the professional and social life of citizens. They have access to a wide volume of information and services and have more free time, as a significant part of their tasks are taken over by these technologies. Regarding the evolution of big data by 2022, the worldwide big data analytics revenue will be USD 274.3 billion according to a report published by International Data Corporation [34]. The evolution of these disruptive technologies will have a favorable economic impact. Figure 2 shows this relationship.



**Figure 2.** Relationship between disruptive technologies and economic progress.

Huang et al. [35] use the concept of a feeling economy to describe the changes generated by AI. According to them, “AI performs many of the analytical and thinking tasks, and human workers gravitate more toward interpersonal and empathetic tasks”. The number of jobs that involve feeling tasks, such as communicating with people inside and outside the organisation, establishing and maintaining interpersonal relationships, and selling to or influencing others, resolving conflicts and negotiating with others, working directly with the public, training teams [35], etc., exceeds those requiring thinking or mechanical tasks. Unlike the feeling economy, the current stage—the thinking economy—requires a significant amount of time allocated for processing, analysis, data interpretation, decision making, work planning and prioritisation, monitoring and controlling resources, updating and using relevant knowledge, and interpreting the meaning of information. The evolution is allowed by the innovations in the field of IoT, big data, and AI technologies that automate the previous tasks.

### 3. Material and Methods

We have performed a rapid review of available literature on disruptive technologies in smart cities to answer the following research questions:

- (1) What are the disruptive technologies that significantly influence the evolution of smart cities?
- (2) How can these contribute to the development of smarter cities?

According to Cartaxo et al. [36], rapid review offers “reliable content”, fosters “the learning of new concepts”, is “problem-oriented” and provides a “flexible knowledge transfer medium”. We searched in the following electronic libraries: IEEE Xplore, Web of Science, and Scopus. The combination of

phrases was (“disruptive technolog\*” AND “smart cit\*”). We used the truncation technique for the words that can have various endings to include all their forms into the search. The truncation symbol is an asterisk in this case. The publication date or subject area were not restricted to embrace all relevant publications. The results are presented in Table 1.

**Table 1.** Databases, key terms used and results.

Database	Query	Number of Papers
IEEE Xplore	“All Metadata”：“disruptive technolog*” AND “smart cit*” OR “Abstract”：“disruptive technolog*” AND “smart cit*” OR “Document Title”：“disruptive technolog*” AND “smart cit*” (“disruptive technolog*” AND “smart cit*”)	21
Web of Science	Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.	26
Scopus	TITLE-ABS-KEY (“disruptive technolog*” AND “smart cit*”) AND (LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “re”) OR LIMIT-TO (DOCTYPE, “ch”))	42

We filtered publications with the Mendeley Desktop application. The inclusion criteria were being original research or review articles, written in English and covered certain search words. First, duplicates, conference reviews, and announcements of conferences or other events were removed. After this selection, the resulting group comprises 59 papers. Second, we exclude irrelevant papers for research aim. This exclusion reduced the results to 51 articles relevant and reasonable for our research. After the screening process, the full text of studies fulfilling the inclusion criteria was downloaded and the content of these texts was examined to establish the extent to which they are appropriate for this research. From these papers, we identified the most important disruptive technologies that support the evolution of smart cities. The word cloud presented in the next section highlights these technologies, based on the analysis of the title and abstract of the selected articles. To faithfully present their contribution to the development of smarter cities, we completed the research with other references, specific to each disruptive technology. They are described in the next sections together with the fields of application and their positive and negative impact on the city’s development. The qualitative evaluation of these publications aimed to form an image on the contribution of the disruptive technologies that significantly contribute to the development of smart cities, as well as the key challenges that arise in their use.

#### 4. Results

The first step in the analysis of the selected articles was to identify the most important disruptive technologies. Based on the fact that Ullah et al.’s. [8] classification corroborated with the results obtained from the analysis of the selected articles, we considered the following four disruptive technologies with major implications for the development of smart cities: IoT, AI, big data, and blockchain. To identify these technologies, we generated the word cloud presented in Figure 3 based on the titles and abstracts of the selected articles. The cloud highlights both the technologies considered disruptive for smart cities and their main areas of application such as ‘vehicle’, ‘transport’, ‘life’, ‘vehicle’, ‘economic’, ‘mobility’, ‘sustainable’, etc. However, their potential is much greater, as shown by the results presented in the following sections. The cloud was generated from the 100 most used words and the common ones were removed. The cloud shows also the main challenges and concerns in the development and implementation of these technologies: architecture, environment integration, citizen privacy, infrastructure, collaboration, and sustainability.

Next sections present, with examples, each disruptive technology, IoT, AI, big data and blockchain, and their specific applications in smart cities.





**Table 2.** Applications of Internet of Things (IoT) in smart cities.

Smart Economy	Smart Mobility	Smart Governance	Smart People	Smart Living	Smart Environment
Industry monitoring [10]	Traffic management [11,41]	E-government [43]	Education [44]	Entertainment [23]	Air pollution [45]
Infrastructure monitoring		E-procurement [46]		Healthcare [16]	Noise monitoring [23]
Efficient transportation planning [41,47]		Utility management [23]	Entrepreneurial opportunities [48]	Emergency services [49]	Waste management [50]
Food and agriculture [51]	Smart parking [52]	Defense [18]			Building management [53]
Radiation and electromagnetic level [54]	Quality of shipment conditions	Public safety [18,23]		Surveillance [23]	Radiation and electromagnetic level [54]
Smart lighting [55]		Public services [43]			
		Efficient energy consumption [4,53]			
Wine quality	Vehicle auto-diagnosis [56]	Cultural facilities [4]	Smart home and office [17,23]		Forest fire detection [40]

The development of hyperconnected, ubiquitous networks of devices involves taking into account all their components and characteristics. Intel [43] identified six dimensions of policy principles for the development and use of IoT technologies: connectivity and interoperability, privacy and security, intelligent analytics and big data, open standards, data, and device discoverability, and public and private partnership. However, IoT generates a large volume of data, many of them partially structured or unstructured. As a result, there is a need for more advanced technologies to store, process, and analyse these data, to extract and synthesise relevant information and to make decisions and initiate actions based on the results. Big data and AI are these technologies.

#### 4.2. Big Data and Artificial Intelligence

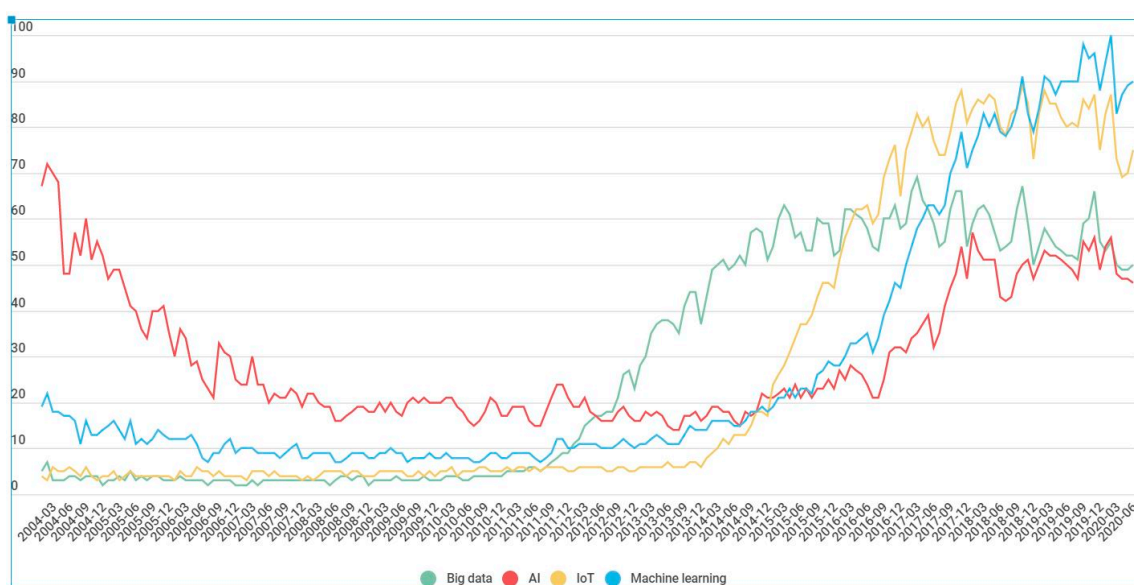
The evolution of AI is closely linked to the development of big data technologies in the opinion of researchers [57–59] since they complement each other. AI becomes better as the volume of data acquired increases, and big data is useful only together with software to analyse it. These technologies offer the possibility to collect and make useful the information provided by devices connected by the Internet. Since we agree with this approach, we present them together in this section of the paper. Sensor networks generate a huge volume of data. Big data technologies allow for their management. According to Thakuriah et al. [60], big data “refers to structured and unstructured data generated naturally as a part of transactional, operational, planning and social activities, or the linkage of such data to purposefully designed data”. Some authors consider big data a strategic economic resource similar in importance to gold and oil [45].

The sources of big data are directed data generated by traditional forms of surveillance and, in this case, the technology is focused on a person or place by a human operator, automated data generated by devices or systems, and volunteered data generated by users [61]. After data collection or receipt, big data analytics and algorithms are used to process and analyse the data to identify and extract useful information for different users, people, or machines [40]. As a result, big data technologies are indispensable for IoT operation in smart cities. They are not, however, without problems and challenges. According Colding et al. [62], big data analytics have “a huge potential to enhance smart city services; however, the combination of the IoT and big data is still an immature, unexplored research avenue, with new challenges for achieving the goal of the smart city”. They facilitate, for example, the involvement of citizens who can become providers of information. According to Neirotti et al. [27], citizens’ knowledge is a rich source of up-to-date information and could improve the quality of urban

space analysis, compared to traditional forms of spatial planning. This option can be considered an extension of democracy and increases the chances of accepting local development plans.

Big data analytics is possible due to the evolution of AI. In smart cities, their use can provide a variety of economic and social benefits, from traffic decongestion and parking, optimizing energy consumption, healthcare and security, to changing the way citizens live every day, interact and work [18]. The accuracy of the results is conditioned both by the performance of the applications used to interpret the data and by the volume of available data.

The beginning of AI in the early 1950s was followed by periods of growth, stagnation, and decline. Recent studies show a close relationship between big data technologies and AI evolution [57,59]. Figure 4 presents an analysis from Google Trends [63] on the popularity of big data, AI, machine learning, and IoT between 2004 and 2020. Between 2004 to 2008, a decline in AI is observed, followed by a period of moderate evolution until 2011 and another decline between 2011 and 2014. After 2014, AI's popularity rises again. These changes overlap with a significant increase in big data popularity.



**Figure 4.** Popularity of the concepts of big data, artificial intelligence (AI), IoT and machine learning based on their searches between 2004 and 2020 [63].

AI has a variety of subfields, such as robotics, NLP (content subtraction, question answering, classification, machine translation, and text generation), expert systems, speech recognition (speech to text and text to speech), vision (image recognition, machine vision), etc. Big data technologies allow or the collection of a very large volume of data from all networks. A wide variety of devices and sensors are integrated into the infrastructure. The data obtained are processed using AI-based software by applying advanced analyses. The results are used, finally, to improve the citizens' quality of life. They will enable better results to be provided for long-term strategic planning, better public services, and better use of resources [64]. Machine learning, for example, needs a wide volume of data to ensure correct results. Big data can provide access to this data. Together with IoT and AI, big data have the potential to make smart cities more efficient and responsive [65] provided they are integrated into a physical infrastructure which, by itself, both through the production and use process, optimises the consumption of resources and reduces the negative impact on the environment. Some examples of AI and big data-based applications are presented below. In Glasgow, a network of sensors uses AI and big data to connect streetlight and traffic lights to support monitor traffic flows and increase connectivity to reduce travel time, including making decisions to plan the commutes [66]. The Seattle Police Department launched a platform for police officers' activities management to track actions such as use-of-force incidents, the number of arrests, self-initiated trips, response to calls, the number of stops,

and civilian complaints [67]. London Metropolitan Police use facial recognition technology to identify suspects [68]. The Las Vegas Health Department uses machine learning to collect and examine tweets to select restaurants where inspections are required to prevent foodborne illness [69]. Big data and IoT help to improve the sustainability of smart cities through visualisation techniques. They provide tools for collecting, processing, and presenting the necessary evidence to make strategic and tactical decisions taking into account the expertise of users and facilitating their understanding [70].

Applications based on AI and big data technologies are used to improve knowledge, teaching and learning tools, as well as quickly updating the curriculum by accessing a wide variety of scientific information according to economic and social requirements; to identify patterns of traffic to anticipate future traffic and control traffic lights [5,71]; community energy management, building energy management, and electric vehicles [5]; waste management (trash collection locations and times scheduled) [72]; healthcare to predict contagious diseases and epidemics and ubiquitous availability of citizen's health data [16]; understanding, monitoring, regulating and planning for better city management [61]; real-time video image processing to identify lawbreakers [73] or video-based real-time intrusion detection system [74] to increase the safety of citizen. AI and machine learning are very important to precisely monitor and estimate the real-time traffic flow data in urban environments [19]. In healthcare, AI and big data analytics help with the evaluation of the general health conditions of patients, hospital disinfection, creation, understanding and classification of clinical documentation, cancer prognosis and prediction, rapid intervention in emergencies, surgeries, assistance for seniors, treatment, perform tasks for administrative purposes, etc. Table 3 presents a selection of big data and AI applications in smart city components.

**Table 3.** Applications of AI and big data in smart cities.

Smart Economy	Smart Mobility	Smart Governance	Smart People	Smart Living	Smart Environment
Support business decisions [58]	Traffic management [14,19]	E-government [9,61]	Education [75]	Entertainment [76]	Water quality [77,78]
Smart lighting [5,79]		Planning [70]	Healthcare [16,80]		Disaster prevention [70]
Automating the data management process [81]	Transport congestion [9]	E-procurement [46]	Entrepreneurial opportunities [48]	Crowd monitoring [73,74]	Air quality prediction [82]
Complex statistical analyses [81]	Smart parking [83]	Public safety [73,74]	Social comfort [57]		Building management [84]
Perform repetitive tasks [9]	Vehicle auto-diagnosis [9]	Efficient energy [5,84,85]	Smart home [86]		Waste management [50,72]

According to Guevara et al. [38], big data and IoT due to 5G technologies will gather more useful information for citizens. The automotive industry is an example of an industry with major benefits brought by the evolution of AI and IoT. All big companies such as Audi, BMW, Daimler, Mercedes-Bosch alliance, Delphi, Didi Chuxing, Ford, General Motors, Honda, Huawei, Hyundai, Jaguar Land Rover, Lyft, Microsoft, nuTonomy, PSA, Renault-Nissan alliance, Samsung, Tesla, Toyota, Uber, Volkswagen Group, Volvo, Waymo, ZF and Zoox work on the development of connected and autonomous vehicles [56]. They will have numerous benefits for users from creating more free time to increasing traffic safety and accident prevention and will create safety smart cities.



### 4.3. Blockchain

Along with big data and AI, blockchain has developed as a technology that contributes to increasing the intelligence of cities. This is described as a distributed, replicated, and secure digital register that allows contracting parties to see a system of records that are immutable [57]. Blockchain has evolved rapidly. Now it has reached version 4.0, which aims to integrate this technology into the industry to meet all the business needs of users, even if they use different platforms. It encompasses all applications of blockchain technology that is not limited to cryptocurrencies, such as electronic voting, healthcare records management, identity management, decentralised notary, etc. [87]. Given the diversity of financial and contractual transactions that occur in the case of urban governance, as well as the large number of parties involved, the use of blockchain technologies can bring considerable improvements. Furthermore, blockchain technology can enhance trust in data since technology is encrypted and secure [57]. Smart contracts can be used by smart city administrations to overcome bureaucratic difficulties and political issues. In this way, they reduce the amount of time required in developing projects. According to Marsal-Llacuna [88], “blockchains’ virtual and physical networking symbiosis through smart contracts empowers citizens for a bottom-up delivery of codes, owned and implemented by them and not by a central authority. In 2018, 60% of the market value of blockchain belonged to the financial sector, but it spread rapidly in other industries, such as health and agriculture [33]. For example, Hırta et al. [14] designed a reputation system based on blockchain technology for intelligent transport systems. Users contribute with data to the system and receive real traffic information. The system evaluates the behavior of enrolled users before integrating the received data based on data received from every vehicle. It was tested on a traffic simulator that can simulate thousands of cars in real city environments (for Rome, Beijing, and San Francisco, in this case).

A PWC report [89] on the application of blockchain technology in smart cities estimates that, together with IoT, AI and machine learning, will lead to a significant improvement in urban governance. According to the same report, cities will be characterised by prosperity, stronger and interconnected communities, healthier people, positive growth, and increased social mobility at an unprecedented level [89]. Blockchain can be used for the decentralisation of voting platforms for local elections and legislative issues; providing transaction security in decentralised smart grid energy trading and real-time and flexible pricing [22,90]; in intelligent transport systems to create better usage of the legacy infrastructure and resources [15], to provide a secure communication platform for smart cities; to control and configure devices in IoT [91]; security and energy efficiency in smart homes [17], storing the medical data in an immutable and secure manner and flexible access of the patients and doctors to their medical records; in supply chain management for data sharing tracking the detailed product information as a counterfeit product detection system; and providing on-demand, personalised and integrated services [22]. Table 4 presents a selection of blockchain applications in smart city components.

**Table 4.** Applications of blockchain in smart cities.

Smart Economy	Smart Mobility	Smart Governance	Smart People	Smart Living	Smart Environment
Access control system [87]	Vehicles communication management [92]	E-procurement/ Smart contracts [46,89]	Personal data management [92]	Healthcare [22,92]	Air quality monitoring [93]
Shipment tracking [92]	Transportation planning [14,47]				
Agriculture [94]	Traffic management [14]	E-voting [89]	Smart home [17,87]		
Transaction history management [92]		Public safety [91]			
		Smart grid energy [22,90]			

Blockchain technologies are just beginning but offer many opportunities for the development of smart cities due to their characteristics, such as decentralisation, audibility, immutability, and transparency. They are complementary to big data and AI technologies that alone cannot guarantee data quality due to threats such as hacking and human mistakes [88]. By integrating them with blockchain, users' trust in data will increase.

## 5. Discussion

This study conducts a review of disruptive technologies in smart cities. The research investigates the available literature under the following constraints: English language, three database sources (IEEE Xplore, Web of Science, and Scopus), research and literature review papers only, focus on disruptive technologies and smart cities with limited variants on search keywords. The results facilitated the discussion on current status and progress on the topic of the paper.

Smart cities, through their citizen, integrate IoT, AI, big data, and blockchain into real daily life. The following main points and critical issues are disclosed by our research:

- The disruptive technologies have the potential to generate positive changes in the smart city by promoting sustainable economic and social activities.
- IoT, AI, and big data are useful in automating decision making and problem solving and support the development of smarter cities.
- Blockchain increases the trust in data proving a secure communication platform and better usage of the legacy infrastructure and resources.
- The literature on disruptive technologies in smart cities associates these technologies, especially with AI, big data, IoT, and blockchain.
- AI, big data, IoT, and blockchain are interdependent and complementary and provide support for all other emerging technologies used in smart cities (wearable tech, social robotics, virtual and augmented reality, 3D printing, digital twins, etc.).
- Disruptive technologies in the actual context of smart cities mainly concentrate on mobility and transport, environmental sustainability, health, security, business efficiency, energy efficiency, and education.

The results of the review reveal that disruptive technologies have a profound impact on smart cities, both on physical setup and operational level. They must adapt to the diversity of citizens' problems and needs, to the variety of environmental conditions, and possess a degree of transparency. They also must have the technical performances required by well-trained and more selective users. The level of acceptance of technological innovation will be influenced by the level of trust individuals and companies in these technologies. In this context, it is very important for the final users' implication in their development. They may be allowed to customise applications and devices according to their own needs and lifestyles. Thus, they become not only users but also providers of innovation and increase the chances of assimilating it in everyday life. An important feature of the technologies analysed refers to their contribution to the data security and citizens' safety. These issues are increasingly critical and blockchain is coming with important improvements. The European Commission [95] underlined seven key requirements for the successful use of AI, (1) human agency and oversight, (2) technical robustness and safety, (3) privacy and data governance, (4) transparency, (5) diversity, non-discrimination and fairness, (6) societal and environmental wellbeing, and (7) accountability. They are also applicable to the other disruptive technologies presented in this paper considering the strong relationship between them. The success of disruptive technologies deployment to make cities smarter depends on the citizens' knowledge and interest to keep public and personal values in their adoption [81]. As can be seen from the previous section, there is a wide variety of areas that use applications based on IoT, AI, big data, or blockchain. For each disruptive technology, we present a selection of applications to create the premises for identifying other potential uses.

However, the ubiquity of ICT also has some disadvantages. There are opinions against this trend, argued by the negative effects on the environment, the limitation of human contacts, deculturalisation, etc. According to Allam and Newman [96], smart cities are often described as the “magic bullet” to all urbanization issues.

Each of the three disruptive technologies presented above has its critics. For example, in the case of big data, Mattern [97] estimates that it suffers from “data-fication, the presumption that all meaningful flows and activity can be sensed and measured”. It is necessary to maintain a balance between technology and the real needs of the city translated by citizens’ needs and environmental protection. Big data allows for the more efficient and dynamic collection and management of various aspects of the city, but a series of safe and sustainable tools, policies, and practices to regulate urban life must complement and validate the innovation in this field.

Confidentiality is another important issue to study when considering the issue of collecting and accessing all data in the smart city. According to Hough [98], privacy has four components: solitude, intimacy, anonymity, and reserve. Regulatory organisations must provide the legal framework to protect the population for each component, but it is quite difficult to predict all possible violations [57]. The technologies used to implement, smart office, smart house and smart health allow access to a wide variety of private information [99]. It is very important not to limit or influence citizens’ free will. Moreover, educating citizens to be aware of the boundary between public and confidential information is very important. Otherwise, data can be used to invade their privacy or to manipulate them [100]. Another important aspect is the impact on the environment. According to Beck et al. [21], it is necessary to analyse the environmental implications of powering an expanding network to support the computing power required for blockchain operation. For example, mining bitcoins requires very high and growing energy consumption [101]. Other aspects that should be considered are the distribution of wealth, predominant social arrangements, and geopolitical balance [21]. Moreover, millions of interconnected devices involve the consumption of non-renewable resources for their development. The energy consumption is difficult to estimate globally, and e-waste is difficult to recycle. A study to assess the relationship between the production process in this area and the real usefulness of products is very difficult to achieve but is very useful.

## 6. Conclusions

This study offers a novel contribution to the literature by mapping out the landscape of disruptive technologies and smart cities. According to the United Nations [102], by 2030, the world is projected to have 43 megacities with more than 10 million inhabitants. In this context, more and more cities have to become smart or smarter. This study aimed to reveal how disruptive technologies, IoT, big data, AI, and blockchain, in this case, contribute to the progress of smart cities. The raising of the technological level of cities is not a goal. It is the driver. The goal of financial and human investment in ICT must be the optimization of the city’s functions. The smart city must be smart through the long-term well-being of citizens. This depends on the level of digitisation, but the use and usefulness of ICT in everyday life are overestimated. Over time, this can lead to a loss of privacy, a lack of focus on important goals, an irreversible negative impact on the environment, and deficiencies in the capacity to integrate into society. As a result, the existence of technological limitations is very important. However, it is obvious that, beyond these potential dangers, disruptive technologies bring invaluable benefits to smart cities as presented in this paper. The broad finding of our review findings reveals that: (1) the potential of IoT, big data, AI, and blockchain to provide positive changes in smart cities is huge if they are used with responsibility; (2) these technologies are interdependent and complementary, and will evolve together. The specific findings are: (1) IoT, big data, AI, and blockchain are the most significant disruptive technologies for the evolution of smart cities; (2) they are emerging fields of research and practice in the context of smart cities; (3) the central focus of the literature in this field is on their application in mobility and transport, environmental sustainability, health, security, business efficiency, energy efficiency, and education and less on their risks.

This article is not lacking in limitations. One limitation is the strictly theoretical character and another limitation is associated with the features of the rapid review. To address this, we searched the most representative databases for papers to score a reasonable pool of relevant results.

Successful implementation of these technologies involves collaboration between the public and private sectors, between government organisations and citizens, as well as between universities and companies to ensure a natural evolution, informing citizens about the benefits and risks of using ICT, studying the psychological impact, and establishing responsibilities both ICT developers and users. IoT, big data, artificial intelligence, and blockchain are just some of the disruptive technologies that underlie the evolution of the smart city. Gamification, wearable tech, social robotics, virtual and augmented reality, 3D printing, digital twins, etc., are other disruptive technologies developed based on technologies presented in this paper and will be the subject of future research.

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Article

# Linking Dynamic Building Simulation with Long-Term Energy System Planning to Improve Buildings Urban Energy Planning Strategies

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**Abstract:** The building sector is currently responsible of 40% of global final energy consumption, influencing the broader energy system in terms of new electricity and heat capacity additions, as well as distribution infrastructure reinforcement. Current building energy efficiency potential is largely untapped, especially at the local level where retrofit interventions are typically enforced, neglecting their potential synergies with the entire energy system. To improve the understanding of these potential interactions, this paper proposes a methodology that links dynamic building simulation and energy planning tools at the urban scale. At first, a detailed bottom-up analysis was conducted to estimate the current and post-retrofit energy demand of the building stock. The stock analysis is further linked to a broader energy system simulation model to understand the impact of building renovation on the whole urban energy system in terms of cost, greenhouse gas emission, and primary energy consumption up to 2050. The methodology is suited to analyze the relationship between building energy demand reduction potential and clean energy sources' deployment to shift buildings away from fossil fuels, the key priority for decarbonizing buildings. The methodology was applied to the case study city of Torino, Italy, highlighting the critical role of coupling proper building retrofit intervention with district-level heat generation strategies, such as modern district heating able to exploit low-grade heat. Being able to simulate both demand and supply future alternatives, the methodology provides a robust reference for municipalities and energy suppliers aiming at promoting efficient energy policies and targeted investments.

**Keywords:** urban energy planning; EnergyPLAN; district heating; dynamic building simulation; future scenario analysis; energy modelling tool

## 1. Introduction

In the last decade, several actions were deployed to contrast climate change. According to the IEA [1], addressing climate change it is necessary to limit global warming well below 2 °C beyond preindustrial levels in 2050. The European Union, in 2009, decided to plan a reduction of greenhouse gas (GHG) emissions to at least 80% below 1990 levels by 2050. To achieve this goal, the European Climatic Foundation redacted a study analyzing the feasibility of this target [2]. With the new European Green Deal [3], ambitions to reduce CO<sub>2</sub> emission are growing, setting the reduction target for 2030 to 55% and aiming to achieve a net zero emission in 2050. For a future decarbonized energy system, the first step will be improved energy efficiency, especially in building patrimony. Energy consumption of the building sector is 40% of total European energy use, accounting for 36% of associated energy related CO<sub>2</sub> emission [4]. In some areas, space heating accounts for a larger quota of building energy consumption, up to 80% in colder climates [5]. The low energy performance of existing long life

building envelopes are among the major causes of this consumption. A total of 67% of buildings in Europe were built before energy efficiency regulation, and 50% of individual heating systems are fossil fuel boilers with energy efficiency even lower than 60%. For this reason, energy efficiency measures cover a fundamental role in buildings, starting from the renovation and insulation of building envelopes to the improvement of energy systems' efficiency. To strengthen the commitment to building energy saving, in 2017 each European nation delivered a national energy action plan for the 2017–2020 period, using the Directive 2010/31/EU on the energy performance of buildings as a guideline to state new policies and targets for the building's retrofit and the energy efficiency [6].

Energy planning actions on the building sector require, first, the assessment of current energy consumption of the stock and its potential cost-effective energy savings. Many planning approaches consider the energy demand at an aggregated level, where the energy savings potential can be estimated as a percentage reduction of total consumption derived by a gradual achievement of compliance to current regulation as in [7,8].

Detailed analyses to disaggregate the residential stock into different building archetypes or down to the single building level have been developed by several approaches in the last year. The initial approaches were based on census data for statistically distributing buildings consumption according to primary energy use for heating, as proposed by Fracastoro et al. [9]. More recently, heat atlas methodology was used to quantify and locate heat demand in buildings according to climate and building footprint ([10,11]) However, as underlined by Petrović et al. in [12], this approach considered a predefined heat demand reduction and did not analyze heat saving in detail. A solution to this lack of details was proposed in [13] by applying a spatial approach, in which geometrical data coupled with statistical analysis were used to identify building archetypes to which an energy demand is associated through real energy consumption data or by using energy simulation software. The same approach was followed in [14,15], with further calibrating of the bottom-up approach with top-down data. A higher level of disaggregation was reached in the work of Monsalvete et al. [16], in which a modular physical building model was developed in INSEL8 (Integrated Simulation Environment Language) and it was connected with the CityGML urban geometry data model.

These methodologies assessed the energy demand and savings potential of the building sectors with different level of disaggregation, however their application for energy planning purposes is limited, often neglecting heat supply options. The importance of finding a balance between heat savings and heat supply was stressed by Hansen et al. [17], who showed that energy saving measures are less efficient without a related change on the energy production.

Energy interventions planned with a systematic approach can lead to enhanced synergies and flexibility throughout the energy system, in particular in urban areas, which are relevant consumption hubs. In Europe, heat is usually supplied by individual boilers, mostly fossil fuel burning, which in future are expected to progressively shift to electricity (e.g., heat pump) [2], increasing the need for coordination between heat generation and heat networks and the electricity grid. District heating (DH) provides 9% of the EU's heating [5] and presents several advantages thanks to the possibility of integrating different heating technologies and sources [4], including geothermal heat pumps [18], solar energy, and waste heat, as well as conventional sources. Connolly et al. [19] analyzed the advantage of connecting individual heating systems within a heating network in a potential 100% renewable scenario for the European Union. The study found that district heating networks are generally more energy efficient in urban areas, reducing gas emission without relevant additional cost. The penetration of DH networks in energy systems provided evidence to achieve energy savings goals thanks to the utilization of different energy sources, reducing the emphasis on deep heat-saving measures that are often cost prohibitive [20].

Integrated demand–supply analyses are often supported by energy system tools. Connolly et al. [21] provided a review of major energy system tools and their applications. As one of the more widespread, EnergyPLAN can be used to analyze an entire energy system, dividing demand and supply into sectors [19,22]. In the new digital era, with digital technologies taking over the

management of energy sectors, due to its intuitive interface and simple data requirement, this tool can be used for urban application, with it being more understandable to urban stakeholders compared to other energy planning tools (e.g., IMEAS project [23]).

A complete overview of the overall energy system allows municipalities to handle future urban energy planning policies, developing a central role as mediator between different stakeholders from different sectors, being able to lead the construction of a common pathway for achieving future decarbonization goals.

At regional level, this tool was applied in Hong Kong [24], while at the city level, it was applied by [8], underlining that the tool considers only aggregate heat demand and also aggregate supply, with it not being detailed enough to describe alone an urban energy system. To meet the need of a better demand description in urban areas for reflecting the real status of the building stock and to integrate demand–supply analyses, this paper’s goals were threefold:

- (1) Develop a spatial-based methodology to represent the urban building demand;
- (2) Link the results of the urban stock analysis with an energy planning tool to analyze both demand and supply decarbonization measures and their economic impact;
- (3) Apply the integrated tool to develop scenarios to support integrated energy planning strategies of an urban municipality.

While urban building stock studies focused on building renovation scenarios are common in literature [25,26], the implications and synergies of demand measures on the supply side are often neglected in urban analyses [27]. The main innovation of the methodology described in this paper is indeed related to its integrated structure, targeting urban analyses and providing an in depth analysis of the energy consumption of entire building stocks and potential energy refurbishment measures, including an additional analysis about the implication that a change in the demand side could have on the supply sector over the long term.

The integrated analysis was performed over a medium-long term period to help urban energy planners in defining technically feasible and economically affordable future energy efficiency scenarios in terms of CO<sub>2</sub> emissions, primary energy supply, and total annual cost. The integrated demand-supply analysis proposed was applied to a case study, the city of Turin. Future scenarios to achieve energy savings goal include the expansion of the existing district heating network of the city and the introduction of renewable energy technologies in the supply.

This paper is structured in four sections: the first one analyzes the case study, the second one explains the methodology, and the third one presents and analyses the results. The applicability of the methodology, the necessary conditions, and its limits are further discussed in the last section.

## 2. Case Study

The methodology was applied to the case study city of Turin. Turin is a city situated in northern Italy, with 2706 heating degree days (HDDs) at 18 °C. According to previous literature, heating volume of residential building is almost 139 Mm<sup>3</sup> [28]. Almost half of the heating volume is satisfied by individual natural gas boilers, while the remaining volume is connected to district heating. The district heating (DH) in the city is the largest in Italy, with 550 km of pipes line and a building volume of 60.3 Mm<sup>3</sup> connected to it. The heat production is satisfied for 98% by three different cogenerating thermal plants administrated by IREN Energia [29], with a total of 1200 MW electrical power installed and 740 MW thermal power. The remaining heat need is satisfied by natural gas boilers, with a thermal power installed of 1000 MW. Three thermal storages are distributed in the city, with a total capacity of 430 MW. The expansion of district heating allows for a reduction in energy consumption and the integration of renewable energy sources, without a relevant impact in the total cost, as explained in the introduction. For this reason, the following study was concentrated on the heating volume connected to DH. Real data of heat consumption of district heating were provided by IREN, manager of district heating, for year 2014, with a total annual heat consumption of 1.99 TWh/year (in 2014 district heating

supplied heat to 57 Mm<sup>3</sup>). To evaluate a possible network expansion, another 19.5 Mm<sup>3</sup> were analyzed considering previous literature, as explained in the Section 3.1. The total volume considered in the case study was equal to 76.5 Mm<sup>3</sup>, of which 57 Mm<sup>3</sup> were attributed to the DH (as in the real case) and 19.5 Mm<sup>3</sup> were considered in the base scenario as individual heating, while in future scenarios they will be connected to DH. The assumptions of current and future expansion of the district heating are supported by literature [27,28].

### 3. Methodology

The presented methodology was composed of three key phases. The first one consisted of analyzing the energy consumption for space and water heating of identified residential reference building typologies and the potential for energy retrofit interventions, through dynamic simulation (Section 3.1). As a second step, a spatial analysis based on census data allowed researchers to quantify the distribution of reference buildings within the urban area and consequently to estimate the total energy requirement of the residential stock (Section 3.2). In the last step, the whole energy system was analyzed with an energy system simulation tool [30], allowing researchers to extend the analysis to the supply side and to develop multiple scenarios (Figure 1) (Sections 3.3–3.5).

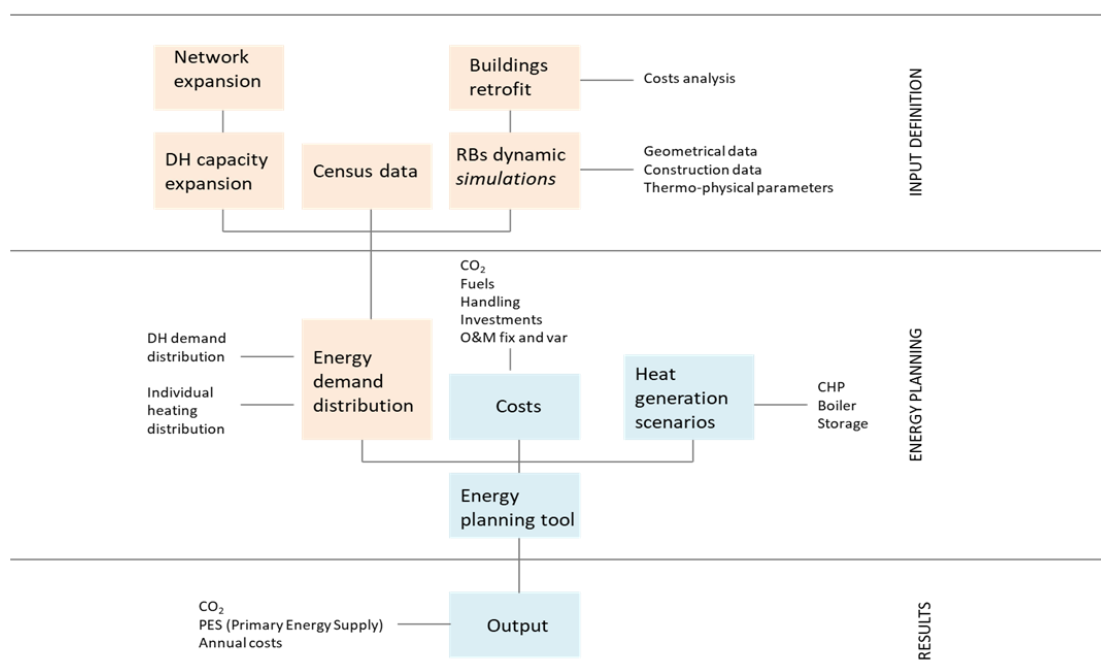


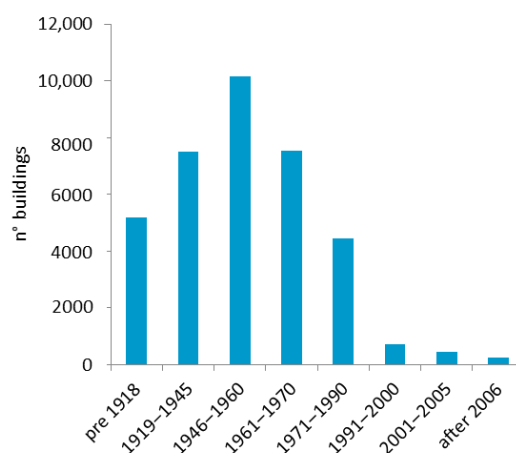
Figure 1. Scheme of the methodology.

During the first phase, the objective was to understand where buildings' energy-saving interventions are a priority (high-energy/high-density areas) and which level of the retrofit intervention can be reasonably pursued. Achieving this type of detail required the use of a dynamic simulation software to analyze the impact of different energy saving measures on heat consumptions. To analyze the built environment, the authors introduced the widely adopted concept of a "reference building" (RB). RBs are "buildings characterized by and representative of their functionality and geographic location, including in- door and outdoor climate conditions" [6]. Simulating a RB requires a lot of data, especially when referring to dynamic simulation [31], usually difficult to find at an urban scale. The international project Typology Approach for Building Stock Energy Assessment (TABULA), 2009–2012, aimed to define European building typologies [32], providing a robust dataset of reference buildings in European countries, including the ones diffused in North Italy. The data from the TABULA project represented a valid support for this analysis.

The spatial distribution of buildings within the urban area was determined thanks to available census data of the city. This allowed us both to estimate the current consumptions of the building stock, but also their variations under different energy retrofit options. The impact of thermal demand variation on district heat generation plants, as well as new individual solutions, can be further studied thanks to the energy planning tool EnergyPLAN [30]. This allows users to analyze how to coordinate the introduction of new heat supply technologies with building energy retrofit, both from a technical and economic perspective. The presented methodology was shaped to represent a resource for urban planners to analyze in depth buildings energy savings and their effects on the urban energy system.

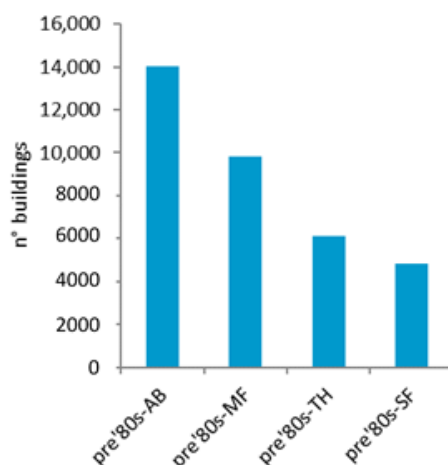
### 3.1. Dynamic Building Simulation and Total Heat Consumption

Turin has 36,158 residential and occupied buildings according to census data, which are subdivided into eight construction classes and four building types (Figure 2).



**Figure 2.** Turin buildings distribution for construction period.

In Turin, almost 96% of buildings were built before 1980, 40% of them are apartment blocks (ABs) and 28% are multifamily houses (MF) (Figure 3). District heating is connected to buildings with a heated volume higher than 2500 m<sup>3</sup> [33], so mostly to AB and MF. For this reason, in this study the chosen reference buildings were apartment blocks belonging to the three most frequent construction periods: ABs built from 1945 to 1960, ABs from 1961 to 1975, and ABs from 1976 to 1990.



**Figure 3.** Pre-1980 building distribution for building type (AB: apartment block; MF: multifamily; TH: terraced house; SF: single family).

For each census section, census data provided information about the number of buildings, in turn separated into four building typologies (AB: apartment block; MF: multi-family; TH: terraced house; SF: single family) and in three age classes (pre-1980, post-1980, post-2005). Also, information about gross heated volume and net surface area were connected to these data.

With the support of GEOPORTALE of Turin [34] it was possible to consult the map with census sections of the city; in this way it was possible to connect territorial distribution of buildings with information about building typologies and construction periods. Considering, for each construction period, a uniform distribution in the city, it was possible to further subdivide census data, and for each section, the number of buildings comparable to the three reference buildings was calculated. Volumes connected to DH were identified, and 30.7 Mm<sup>3</sup> of them could be represented with RBs, in particular: 14.1 Mm<sup>3</sup> belonged to AB 1945–1960, 10.5 Mm<sup>3</sup> to AB 1961–1975, and 6.1 Mm<sup>3</sup> to AB 1976–1990. This subdivision demonstrates the correct choice of reference buildings, because 54% of volumes connected to DH were associable with analyzed buildings.

To evaluate a possible network expansion in relation with energy savings measures, another 43 Mm<sup>3</sup> were analyzed, considering previous literature and assuming that zones near the river were considered not connectable [33]. Of these, 19.5 Mm<sup>3</sup> connectable were represented by RBs: 9 Mm<sup>3</sup> to AB 1945–1960, 6.5 Mm<sup>3</sup> to AB 1961–1975, and 4 Mm<sup>3</sup> to 1975–1990 (Table 1). These 19.5 Mm<sup>3</sup>, considered as individual heating buildings in the base scenario, will be gradually connected to DH in future scenarios.

**Table 1.** Volumes connected to district heating (DH) subject to study and future network expansion.

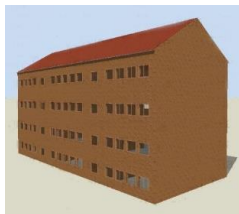
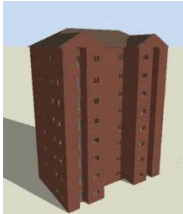

RB Typology	Connect to DH	Possible Expansion
AB 1945–1960	14.1 Mm <sup>3</sup>	9 Mm <sup>3</sup>
AB 1961–1975	10.5 Mm <sup>3</sup>	6.5 Mm <sup>3</sup>
AB 1975–1980	6.1 Mm <sup>3</sup>	4 Mm <sup>3</sup>
tot	30.7 Mm <sup>3</sup>	19.5 Mm <sup>3</sup>

The TABULA project supported the association of thermal characteristics to every RB. The project presented a matrix with 32 different types of building [35,36], and a schedule for each of them containing the heated volume, the floor area, the number of apartments, the number of floors, the surface to volume ratio (S/V), the construction materials with total U-values, energy systems with their energy efficiency, and heat consumption result from steady-state calculation. Other information, such as building shape or number of windows, were derived by author assumptions and set the basis for the following reference building dynamic simulations.

Stratigraphies were hypothesized for roof, floor, and walls (two types of wall were simulated for each RB). A lower insulation was performed, as requested in TABULA ( $U \approx 0.8 \text{ W/m}^2\text{K}$ ), and material data and thermo-physical properties were taken from the Italian National Unification (UNI) standards UNI 10355 and UNI 10351 [37], while for resistances the reference norm was UNI 6946 [38]. All structures neighboring with nonheated zones, as suggested in UNI 6946, provided a superficial resistance equal to the internal superficial resistance for each side. A building layout was created starting from available data of floor area, gross volume of building, and compactness (S/V). RB simulations were performed by DesignBuilder software, a graphic interface based on EnergyPlus™, a building energy simulation program used to model both energy consumption and water used in buildings [39]. Heat energy requirement was calculated following TABULA indications and procedures reported in UNI part one [40], in this way, simulations results could be compared to TABULA results (Table 2), where the difference in energy requirement between the two models was in the order of 1% for each RBs.



Table 2. Reference buildings simulation data.

Reference Building Simulation			AB 1945–1960	AB 1961–1975	AB 1976–1990
					
Geometric data					
Parameter	Symbol	Unit			
Gross heated volume	V	m <sup>3</sup>	5949	9438	
Net floor area	A <sub>n</sub>	m <sup>2</sup>	1763	2869	4123
Shape factor	S/V	m <sup>-1</sup>	0.46	0.46	0.37
N° apartments	-	-	24	40	48
N° floors	-	-	4	8	6
Construction data					
Parameter	Symbol	Unit			
Roof	U	W/m <sup>2</sup> K	1.8	2.20	1.85
Walls	U	W/m <sup>2</sup> K	2.6	1.10	0.76
Lower floor	U	W/m <sup>2</sup> K	1.65	1.65	0.97
Upper floor	U	W/m <sup>2</sup> K	1.3	1.56	0.98
Windows	U	W/m <sup>2</sup> K	4.9 (g <sub>gl</sub> 0.85)	4.9 (g <sub>gl</sub> 0.85)	3.70 (g <sub>gl</sub> 0.75)
Heat need					
Reference building standard		kWh/m <sup>2</sup> y	159	136	66.3
Reference building results		kWh/m <sup>2</sup> y	139	124	61.3

These simulations calculated only the space heat requirements, the “useful energy”, while information about energy system typologies and the relative energy efficiencies were further inserted as input data in the energy planning tool.

The energy analysis performed under the previous assumptions is called “standard” evaluation, but to take in care occupant behavior, the intermittency of heating and the operating schedules of electrical equipment, it was necessary to relax the assumption made following the normative in previous simulation. In literature, several studies have considered the influence of occupant behavior on heat consumption [41,42]. In this paper this argument is not stressed, since the aim was to use reference building to simulate the entire built environment of the city, therefore taking into account a representative occupant behavior pattern. Internal gains as internal light, electrical equipment, and people were aggregated with a single operating schedule, called “internal gain schedule”. Hourly profile of the schedule was extrapolated from UNI 11300 part 1 [40], this was done in order to have a reliable hourly profile.

The simulation results showed a heat requirement of 160 kWh/m<sup>2</sup>/y for AB 1945–1960, 136 kWh/m<sup>2</sup>/y for AB 1961–1975, and 66 kWh/m<sup>2</sup>/y for AB 1976–1990.

The hourly simulation provided for each RB (Appendix B) has been normalized with gross heated volume of RB, as done in [43], and then multiplied for respective volumes (Table 1), creating the total heat profile 60% of the total DH heat demand.

To identify necessary retrofit interventions to comply with new energy efficiency requirements, the authors referred to the environmental energy appendix of building regulation of Turin [44]. In the Appendix A, two restriction levels to thermal insulation are described: the first level is about prescriptive limits, while the second one concerns incentive requirements (an economic incentive

is settled for the buildings that satisfy a higher thermal insulation to further minimize the energy consumption). Heat loads can be reduced using materials with a low thermal transmittance; it is important to define a global strategy for building thermal insulation choosing a correct insulation material and relative thickness (insulation materials chosen related to prospect 2 in UNI:2015 [37], for hygrometric properties the reference was UNI:2008 prospect 4 [45]). It was assumed also that thermal bridges were corrected by retrofit measures.

Three scenarios were created to analyze the energy savings potential in buildings (Table 3):

- Scenario WS: substitution of windows ( $U = 1.20 \text{ W/W}$ ,  $g_{gl} = 0.30$ )
- Scenario SR (standard renovation): all building envelopes are insulated according to transmittance limits in Level 1 [39]
- Scenario AR (advance renovation): all building envelopes are insulated according to transmittance limits in Level 2 [39]

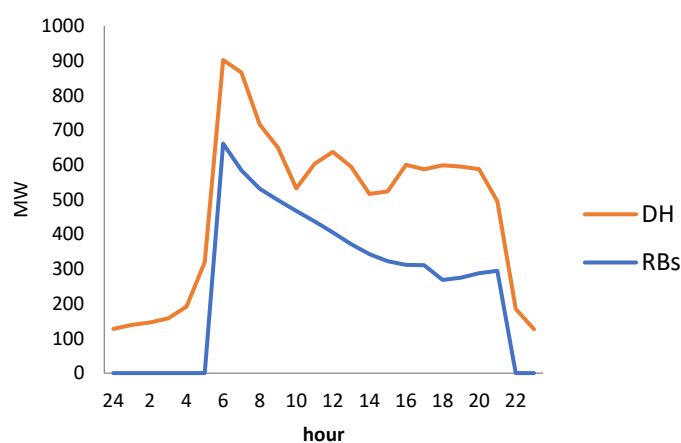
The WS scenario allows the possibility of reaching a 10% of energy savings with respect to base scenario, 80% with the SR, and 88% with AR, considering the application of the energy saving interventions to all the volume connected to DH represented by the RBs ( $30.7 \text{ Mm}^3$ ).

**Table 3.** Heat consumption of reference buildings (RBs) in different scenarios of building retrofit.

Typology	Base (kWh/m <sup>2</sup> y)	WS (kWh/m <sup>2</sup> y)	SR (kWh/m <sup>2</sup> y)	AR (kWh/m <sup>2</sup> y)
AB 1945–1960	158.8	142	29.5	19
AB 1961–1975	135.6	123.4	27.5	16.2
AB 1976–1990	66.3	58.2	17.5	11.3

### 3.2. Modeling District Heat Hourly Profiles

As a second step, the estimated total heat consumption needed to be calibrated to match the urban energy balance allocated to space heating and district heat production. At first, local district heat production was characterized. By analyzing DH real operational data for the years 2012, 2013, and 2014, average heat losses in the network resulted equal to 10% of total heat production. For district heated buildings, the DH quota dedicated to domestic hot water (DHW) was derived by analyzing the summer load; in particular, the average profile of a summer day (in which the heating systems are off according to the Italian normative) was extrapolated from DH real data and chosen as reference for DHW needs and assumed equal for every day of the year. The calculated DHW demand and the losses were subtracted from the total DH demand. By doing this, the remaining DH heat consumption could be compared to the heat profile created through RB simulations (Figure 4).

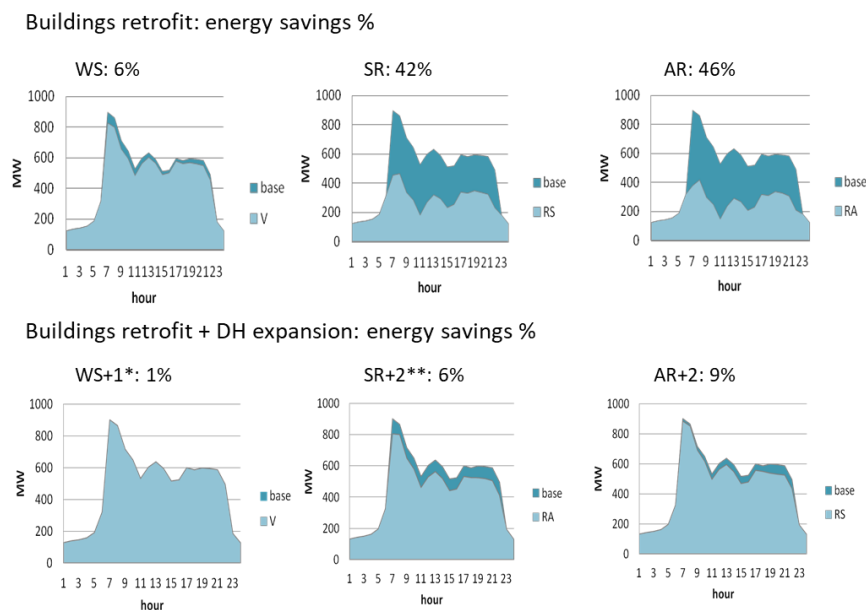


**Figure 4.** DH total real heat profile (red line) compared to RBs total heat profile (blue line) for a day in January. The blue line includes only the heat quote of buildings related to the RBs simulated (covering almost the 54% of the total number of buildings), without the DHW contribution.



Although considering standard values comports uncertainties because both internal loads and infiltration rates are largely influenced by the occupant's behavior (they can vary from building to building, but also from floors of the same building), as analyzed in [46], using a dynamic simulation tool is the best solution for taking into consideration occupant's behavior. Figure 4 validates the results from the reference building simulation, with the simulated heat profile (blue line) being almost 60% of the total DH profile (red line).

Building volumes not connected to DH were considered heated by individual boilers, and with the same method heat profiles were created. Retrofit actions (WS, SR, AR) were gradually analyzed in the same way, and different heat load profiles were compared to DH real data (Figure 5).



**Figure 5.** Energy savings percentage according to building retrofits for different scenarios. \* Scenario 1: DH network expansion (19 Mm<sup>3</sup>). \*\* Scenario 2: DH network expansion 31 Mm<sup>3</sup>.

The decrease of heat consumption comports an increase in heat loss was determined according to Equation (1) [47]. This equation for the estimation of heat losses was previously applied to the same network as in [26,28,48].

$$\begin{aligned} y &= 0.7321 - 1.221x + 0.6462x^2 \text{ if } x < 1 \\ y &= 0.1773 - 0.014x \text{ if } x > 1 \end{aligned} \quad (1)$$

in which  $y$  = loss (%) and  $x$  = linear heat density in MWh/m.

Considering 500 km of pipelines, linear density and the correlated heat losses were calculated for each building's energy saving scenario. In the year 2017, the linear density was equal to 3.5 MWh/m, and it decreased in each scenario. With a line density lower than 2 MWh/m, heat losses were considered too high and the DH network became not convenient. SR and AR scenarios provided a linear density lower than 2 MWh/m, which means 15% of heat loss—to increase the linear density up to 2 MWh/m, network expansions scenarios were associated with retrofit measures for each scenario. For the WS scenario, a lower network expansion was considered, equal to 2.9 Mm<sup>3</sup>, and for SR and AR a higher expansion was supposed, equal to 19.5 Mm<sup>3</sup> (the remaining volume of all buildings with individual heating). This kept the linear density higher than 3 MWh/m in each scenario, and maximum heat losses were in the order of 13%. The heat losses were added to the heat profile consumption of DH and individual buildings and, together with DHW consumption, the heat load profile as input for thermal plant was created (Figure 5).

### 3.3. Energy Savings Costs

Costs associated to energy savings measures were derived from “Prezzario Regione Piemonte 2016” [49]. For each RB, 3 different costs analyses were done, one for each type of building retrofit option (WS, SR, AR). Cost included: construction material/technology cost, installation, and manpower costs.

Analyses with EnergyPLAN also required energy prices and investment cost data as input (investment, operations, fixed and variable maintenance, and manpower costs). Fuels cost, handling costs, and variable operations and maintenance (O&M) costs were also required for each type of technology, together with the eventual CO<sub>2</sub> price and the discount rate (this was assumed equal to 3%). The additional costs, as energy savings measures and network expansion, were inserted in EnergyPLAN in terms of total annual cost (Appendix A).

### 3.4. Global Cost Analysis

The total annual cost provided by EnergyPLAN (according to Equation (2), as reported in [50]) related to a single year in which all investments were supposed to be applied. In this way, it was possible to compare different annual costs provided from different energy efficiency investments, to understand which is the most profitable solution among the considered options.

$$A_{\text{inves}} = (C_{\text{invest}} * i) / (1 - (1 / (1 + i)^n)) \quad (2)$$

with  $C_{\text{invest}}$  = investment costs;  $i$  = interest;  $n$  = lifetime.

Each investment with a different lifetime could therefore be compared as an equivalent annual cost. Total annual costs (M€/yref) were therefore derived by summing  $A_{\text{inves}}$  with fixed and variable annual costs.

To analyze the global cost of each scenario, according to a more realistic distribution of the investment along the timeline, the methodology in [28] and in [14] was followed: a time period horizon was defined (2017–2050) and divided into 3 period steps (2017–2025, 2025–2035, 2035–2050).

The renovation rate of buildings was set equal to 3% for each year starting from 2018, while DH expansion was planned with a year rate of 4% starting in 2025 (Table 4). Investments in thermal plants were planned according to the end-life of each system based on starting year [51,52], as explained in Table 5.

**Table 4.** Building retrofit and DH expansion rate for time period. \* Starting from 2018.

	2017–2025	2025–2035	2035–2050
Building retrofit	3% renovation volume for year *	3% renovation volume for year	3% renovation volume for year
DH expansion		4% connected volume for year	4% connected volume for year

**Table 5.** Thermal plant investments for time period.

	2017–2025	2025–2035	2035–2050
BAU	No investment	New natural gas CHP (662 MW <sub>el</sub> ), new industrial boiler (1000 MW), new heat storage (430 MW)	New natural gas CHP (360 MW <sub>el</sub> )
MOD	No investment	New natural gas CHP (662 MW <sub>el</sub> ), new industrial boiler (1000 MW), new heat storage (430 MW), heat pump (35 MW <sub>el</sub> )	New natural gas and biomass CHP (338 MW <sub>el</sub> )
ADV	No investment	New natural gas CHP (662 MW <sub>el</sub> ), new industrial boiler (1000 MW), new heat storage (1000 MW), heat pump (85 MW <sub>el</sub> )	New biomass CHP (134 MW <sub>el</sub> )

Building renovation rate and DH expansion rate were used to create a heat distribution demand for DH and individual buildings for each time step. Time periods were simulated considering a linear CO<sub>2</sub> cost and natural gas cost evolution, as explained in Section 3.5.

Variable annual costs and fixed annual costs for the three periods were assumed considering a discount rate of 3%; a present value factor (R<sub>i</sub>) was calculated for each mid-year of the time periods (4, 13, 25.5), and the total discounted cost at 2017 was calculated according to Equation (3).

$$C_{\text{tot}} = \sum_{i=1}^{n=3} [(C_{\text{inv}}(\text{RB},i) + C_{\text{inv}}(\text{dh},i) + (C_{\text{fix}}(i) + C_{\text{var}}(i)) * t) * R(i)] \quad (3)$$

with  $C_{\text{tot}}$  = total cost discounted at 2017 level,  $C_{\text{inv}}(\text{RB},i)$  = investment cost for building retrofit on period  $i$ ,  $C_{\text{inv}}(\text{dh},i)$  = investment cost on DH expansion and heat supply on period  $i$ ,  $C_{\text{fix}}$  and  $C_{\text{var}}$  = fixed and variable costs (€/y) on period  $i$  provide from EnergyPLAN,  $t$  = years in period  $I$ ,  $R(i)$  = present value factor for mid-year of each time step.

### 3.5. Heat Supply Scenario

The existing synergy between district heating expansion and buildings' energy retrofit interventions has been demonstrated in several studies [19,20,28]. The production of heat in the DH system is possible through several options: renewable energies (e.g., solar and geothermal), heat pumps, conventional fossil fuels, or even by exploiting waste heat from industrial processes. Taking into account the current heat generation mix of the Turin DH system (more than 90% heat production based on gas cogeneration plants), this study focused its attention on combined heat and power (CHP) technologies and on the integration of large-scale heat pumps and storage. Two scenarios were analyzed, according to [28], considering already planned power plant installation (biomass CHP) and commercial available capacities. In future scenarios, CHP plants could operate to balance the electricity needs of heat pump.

- MOD: moderate scenario, decommission of 260 MWth of natural gas CHP in 2030, replaced by 105 MWth of heat pump, 106 MWth of biomass CHP, and 150 MW of natural gas CHP.
- ADV: advanced scenario, decommission of 260 MW of natural gas CHP, replaced by 250 MWth of heat pump, 106 MWth of biomass CHP, and 530 MW of daily thermal storage.

Biomass CHP was chosen considering the huge availability of biomass, given that the city of Turin is close to the mountain communities, though an analysis on local emissions should be explored.

To compare the proposed demand–supply options with a scenario reflecting current trends, a business as usual (BAU) scenario was considered (any change in heat consumption and production). This scenario was used as a reference to be compared with the other simulations in terms of energy savings, total primary energy supply (TPES), CO<sub>2</sub> emissions, and total annual cost for year 2050. In the BAU scenario, costs for maintenance and replacement of current power plants after the end of their technical lifetime and power plant investment costs were considered, while change in fuel prices and CO<sub>2</sub> price were considered following the same assumptions as the ones made in the Stratego project [22], assumed equally suitable for an Italian context. A linear growth was considered for the carbon price in the scenario timeline, starting with the assumption of a carbon price equal to 6 €/tCO<sub>2</sub> in 2017, as reported in [53], and an optimistic carbon price of 25 €/tCO<sub>2</sub> for 2050, following the hypothesis made on Heat Roadmap 2050, in which a price of 20–30 €/tCO<sub>2</sub> is expected. By combining scenarios on retrofit measures with scenarios on heat generation, different integrated scenarios were created up to 2050 (Table 6).

**Table 6.** Scenario descriptions.

Building Retrofit	WS	Windows Substitution
	SR	Standard renovation
	AR	Advanced renovation
Network expansion	1	2.9 Mm <sup>3</sup>
	2	19.5 Mm <sup>3</sup>
Heat production change	MOD	105 MW HP 106 MW CHP biomass 250 MW HP
	ADV	106 MW CHP biomass 560 MW heat storage

Hourly consumption profiles obtained for individual buildings in the previous section were used as input in EnergyPLAN for describing the future evolution of the heat demand, starting from the current DH real profile provided by the local utility assumed as reference for the scenario BAU. Individual heating systems were considered as supplied by natural gas boilers with an average efficiency of 0.85. Each cost was introduced in the base year simulation for 2017, and a technical optimization (optimizing capacity sizing and energy use) was performed.

The final heat demand (district heated buildings plus individual heating) was 2.65 TWh/y, 1.99 TWh/y for DH and 0.66 TWh/y for individual heating (19.5 Mm<sup>3</sup>). DH demand was supplied by natural gas CHP (1.93 TWh/y) and natural gas boilers (0.06 TWh/y). Total primary energy supply (TPES) was equal to 6.19 TWh/y, disaggregated into 5.41 TWh/y for CHP + boilers and 0.78 TWh/y for individual heating. The primary energy supply was calculated as the fuel consumptions needed from the energy technologies to satisfy the energy demand of the system. The fuel consumption of the plants was calculated by the model considering technologies' efficiencies. CO<sub>2</sub> emissions were 1.250 Mt, and total annual cost (including investment cost, fixed and variable cost, fuel cost, and carbon price) was 295 M€/y.

Three different buildings retrofit scenarios with two different levels of DH expansion options were compared for three different heat supply mixes (Table 7).

**Table 7.** Different combinations of building retrofit, network expansion, and heat production mix.

\* Network expansion: 1. expansion of 2.9 Mm<sup>3</sup>; 2. expansion of 19.5 Mm<sup>3</sup>. \*\* HP: heat pump; CHPB: biomass combined heat and power (CHP); HS: heat storage.

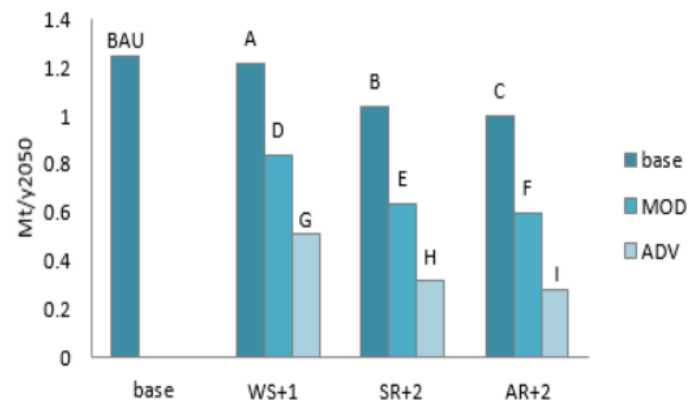
		Building Retrofit (WS,SR, AR) and Network Expansion (1,2) * Scenarios			
		Base	WS + 1 (WS: Windows substitution)	SR + 2 (SR: standard renovation)	AR + 2 (AR: advanced renovation)
Supply side scenarios	Base	BAU	A	B	C
	MOD (105 MW HP **, 106 MW CHP <sub>B</sub> )		D	E	F
	ADV (250 MW HP, 106 MW CHP <sub>B</sub> 560 MW HS)		G	H	I

The scenarios A, B, and C consider the same supply configuration as the BAU scenario, integrating 3 different level of building retrofit. The introduction of a biomass CHP and heat pump (HP) of the MOD heat supply scenario correlated with the building retrofits in scenarios D (windows substitution), E (standard renovation), and F (advanced renovation). The same retrofits were considered for scenarios G, H, and I, together with ADV heat supply scenarios.

As first analysis, the total annual cost of these scenarios was analyzed for the timeline 2017–2050 according to Equation (3).

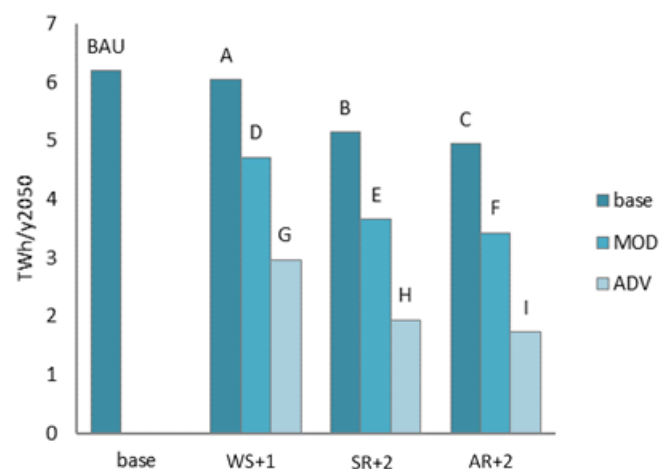
#### 4. Results

At first, the achievable CO<sub>2</sub> emission reduction considering buildings retrofit together with DH expansion without changing in heat supply was analyzed (A, B, C). Compared to the BAU scenario, this reduction is equivalent to 2% for A, 15%, for B and 18% for C (Figure 6). However, demand side measures alone are not enough to achieve 40% emission reductions to 2030, as requested by [54].



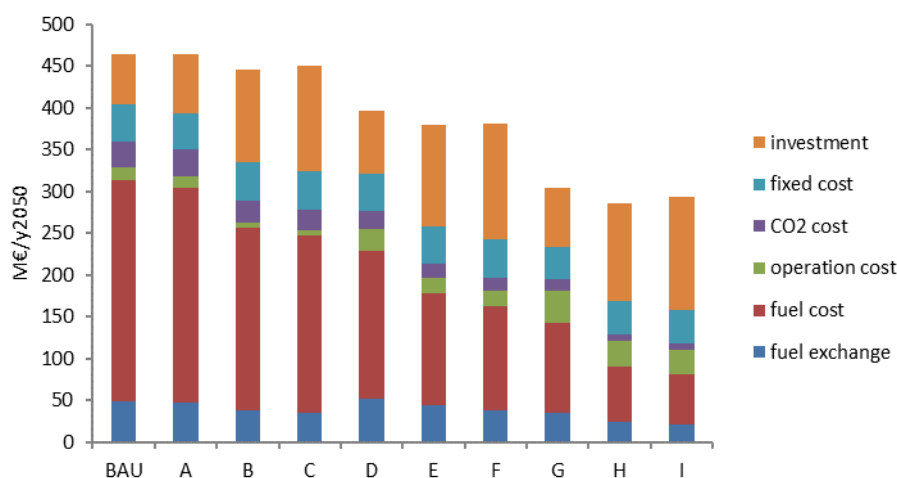
**Figure 6.** CO<sub>2</sub> emissions for different scenarios from EnergyPLAN simulation.

Assuming a “moderate change” in the heat generation mix (MOD scenario) can allow a higher reduction in CO<sub>2</sub> emissions (42%) and TPES (40%), thanks to the integration of heat pumps (HP) and the biomass CHP, relying on low carbon electricity (2050 carbon intensity equal to 0.66 Mt/y), maintaining a natural gas CHP working for 57% of the time in cogeneration mode for heat production. The annual operating time of CHP higher than 4000 h can assure a positive profit for the investment. The optimization algorithm coordinates electricity production by CHP units to heat pumps’ heat generation—CHP operation follows the electricity need of HP and heat storages are used to store CHP heat production excess. This optimization is related to the decision of balancing only the heat consumption, in future studies it might be interesting to study the impact on the electricity market as well. Furthermore, CHP production is primarily satisfied by biomass CHP to reduce the CO<sub>2</sub> emissions. Natural gas consumption and related carbon emissions decrease further with a higher integration of heat pumps in the ADV scenario. Together with the energy savings due to building retrofit measures, the integration of heat pump in MOD scenario guarantees 21% of TPES reduction, while ADV scenario with 250 MW of heat pumps allows a TPES reduction of 49% (Figure 7).



**Figure 7.** Total primary energy supply (TPES) outputs from EnergyPLAN simulations.

Cost outputs were further analyzed (Figure 8) in order to understand to what extent each intervention influences the global cost. In the BAU scenario, total annual costs would be around 460 M€/y in 2050. Fuel cost is the prevalent cost item, covering 58% of total annual costs for BAU.



**Figure 8.** Total annual cost subdivision for each scenario from EnergyPLAN outputs.

Compared to the BAU scenario, each intervention regarding change in heat production (D, E, F, G, H, I) connected with a reduction in heat demand provides a cost decrease. In the scenarios without changes in heat production (A, B, C), fuel costs represent 51% of total costs. In MOD scenarios (D, E, F), this cost voice decreases to 39% and it reaches a minimum value of 27% in ADV scenarios (G, H, I). Lower fuel costs due to fuel shifting in heat production mitigate investment costs for buildings retrofit and for heat generation interventions.

The ADV scenario with standard renovation in buildings, together with DH expansions, provides lower costs with respect to all the other scenarios simulated. Compared to a standard renovation, an advanced renovation on buildings comports a higher reduction in heat consumption, but also higher investment costs. These investment costs are not offset by the savings, highlighting the critical role of defining correct retrofit measures for existing buildings. Meanwhile, considering the very old building stock and the presence of a district heat network, a standard retrofit scenario (H) can provide a better balancing between new investment costs and decreasing costs as a consequence of energy savings measures.

Results from energy system simulations show the synergy between buildings' retrofit interventions and changes in district heating, in terms of network expansion and heat production configuration. From a planning perspective, combining buildings' energy savings with DH expansion strategies, together with the integration of cleaner heat generation technologies as heat pumps, allows significant reductions in terms of CO<sub>2</sub> emission, total costs, and primary energy supply. Larger interventions compared to baseline, as the one proposed in the H scenario, could allow reaching reductions of 78% in CO<sub>2</sub> emission (corresponding to a reduction of 970 MtCO<sub>2</sub>/y) and of 72% in TPES, with benefits in terms of annual costs equivalent to 150 M€/y.

To understand which is the overall marginal cost for the energy system decarbonization in the different scenarios, a "decarbonization cost"  $C_{dec}$  (€/tCO<sub>2</sub>) was calculated, as in Equation (4).

$$C_{dec}(i) = (C_{in}(i) - C_{in}(BAU)) / (CO_2(BAU) - CO_2(i)) \quad (4)$$

With  $C_{in}(i)$  = investments costs for scenario  $i$ ,  $C_{in}(BAU)$  = investment costs in the BAU scenario,  $CO_2(i)$  = CO<sub>2</sub> emission in scenario  $i$ ,  $CO_2(BAU)$  = CO<sub>2</sub> emission in BAU scenario.

The decarbonization cost is the rate between the increasing in investment cost and the CO<sub>2</sub> reduction due to low-carbon measures. It can be used as an index to identify cost-effective decarbonization investments.

From the results, it is possible to affirm that for scenarios with change in the heat Supply (D–I) the decarbonization cost is lower than 100 €/tCO<sub>2</sub> saving, while for scenarios A, B, and C (no change in the heat production mix, but progressive demand reduction thanks to building renovation) the decarbonization cost is almost triple compared to integrated solutions involving the MOD and ADV scenarios (Figures 9 and 10). In scenarios A, B, and C, investment costs are higher than in BAU due to building retrofits, but CO<sub>2</sub> reduction is not enough to justify investments. This consideration is key for building stock retrofits, where the potential for deep retrofit intervention is often limited by technical feasibility or affordability, which needs to be properly defined.

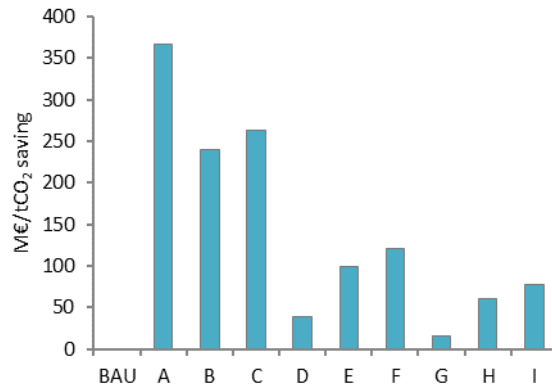


Figure 9. Decarbonization costs in different scenarios.

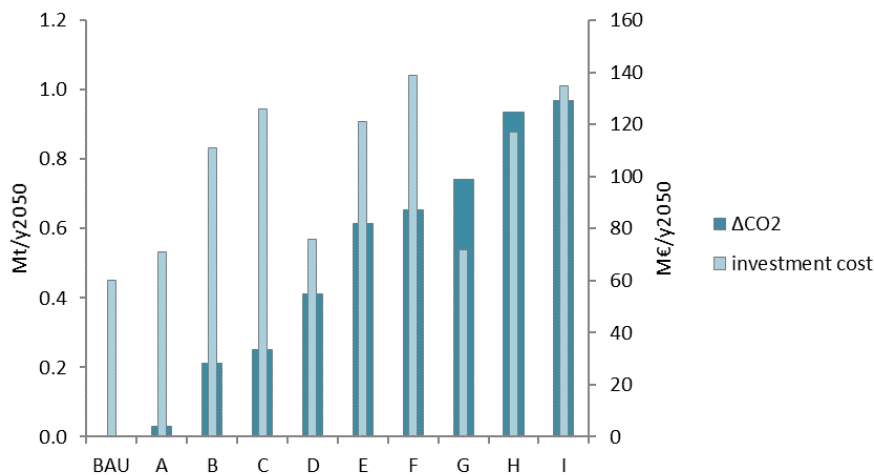
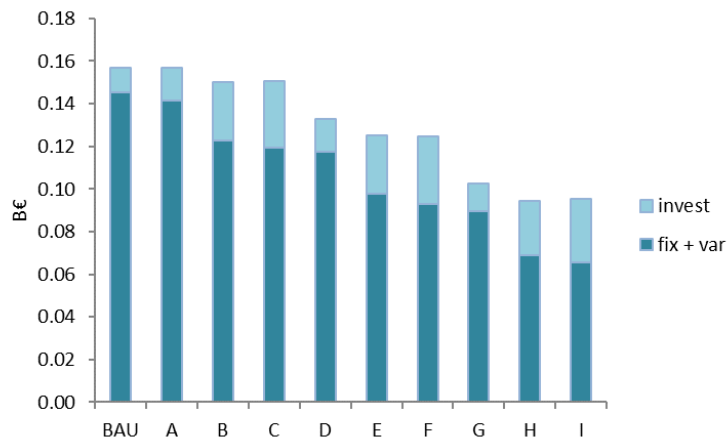


Figure 10. Investment costs and related CO<sub>2</sub> emissions for each scenario.

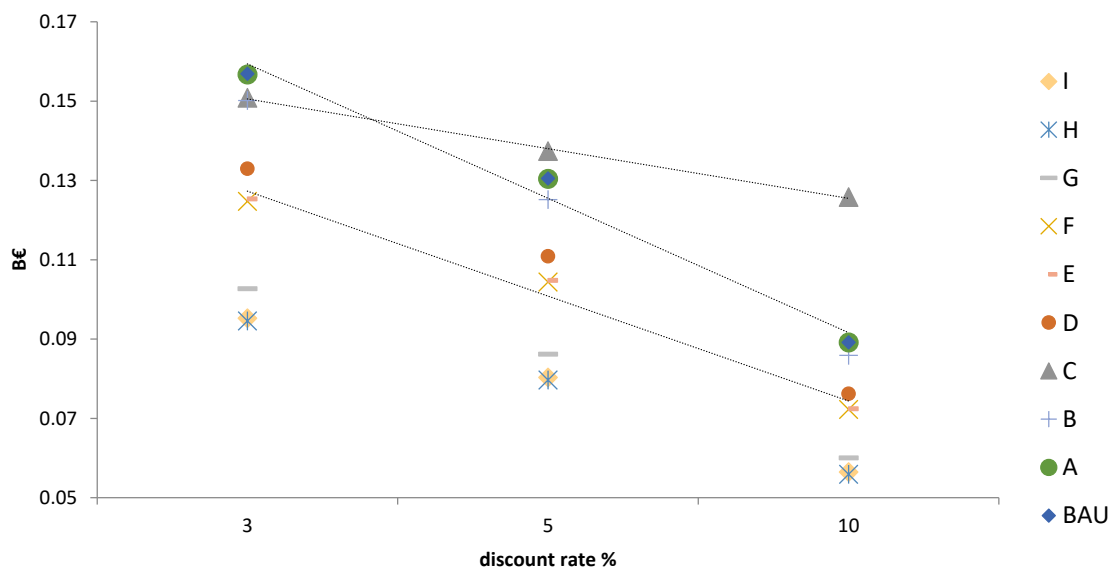
Despite the fact that the cost of decarbonization can already represent a good economic indicator, greater insights can be derived from a more detailed economic analysis that considers the cost distribution over the whole time horizon. As shown by Figure 11, compared with the annual cost analysis performed with EnergyPLAN, a more detailed global cost analysis shows that scenarios with improved heat supply (MOD and ADV) can deliver bigger cost reductions. On the other hand, by applying this methodology, the longer term benefits of advanced building retrofit (C, F, I) can be observed more precisely [55]. This might help to deliver improved energy retrofit considerations.





**Figure 11.** Total costs discounted at 2017 level for different scenarios, divided into investment costs and fix + var costs.

A sensitivity analysis varying discount rates might improve the understanding of which retrofit measures may have reasonable payback times—a lower discount rate presents higher influence of future energy costs, while a higher discount rate presents lower influence on future costs and higher influence of investment costs. In Figure 12, total costs for each scenario were analyzed with different discount rates. Comparing BAU scenario with a moderate scenario (for example E), a higher discount rate comports a lower costs difference between BAU and E, this means that a BAU scenario with few energy efficiency investments can be more convenient with respect to a scenario with bigger energy investments (e.g., E,C) if discount rate increases (or equivalently, without proper policies). Targeted tax policies can represent a useful instrument to push the energy efficiency measures and unlock the necessary fiscal resources for driving a clean energy transition.



**Figure 12.** Discount rate impact on total costs for different scenarios.

### 5. Discussion

Linking energy system analyses to dynamic building simulations to analyze different urban energy patterns connects a data-driven robust building-level analysis with a technology-rich supply-side understanding, allowing researchers catch their interactions. The opportunity to study together the demand side and the supply side allows a better understanding of the decarbonization potential of a city, especially if characterized by an ancient building stock, as in many European cities. A complete



overview of the overall energy system allows municipalities to handle future urban energy planning policies, developing a central role as mediator between different stakeholders from different sectors, being able to lead the construction of a common pathway for achieving future decarbonization goals. The application of EnergyPLAN for national-level studies is well known in literature, but the proposed methodology allows us to expand its use to an urban level without renouncing the level of detail required from the urban environment. The methodology can be further improved considering the increasing data availability in the residential sector (cadaster, smart meters, energy certifications), allowing the calibration of building simulations with real data.

EnergyPLAN was chosen because it provides several advantages: it's a free download tool; on the web page is possible find documentations, guides, and tutorials to help users; input data are easily to find; and it has a user-friendly interface. On the other hand, as previously identified, EnergyPLAN shows some limits in the analyses of the supply side. The technical simulation to balance the heat demands applied by the tool relies on a predefined hierarchy of technologies (solar thermal, industrial CHP, heat production from waste fuel, heat plant CHP, heat pumps, peak load boilers), limiting the possibility of choosing other technology combinations or different parameters to optimize the energy system. Although, this limitation can be overcome by utilizing the MATLAB Toolbox for EnergyPLAN [56]. Furthermore, it requires aggregated input data for production that do not allow users to analyze each thermal plant singularly. and this means that the introduction of a new thermal plant (e.g., biomass CHP in this case study) cannot be analyzed individually. Usually power plants are projected to satisfy different cities, while an aggregated simulation requires a sort of close control volume, in which entry flows and exit flows are well known. However, these uncertainties are limited for the previous case study because the studied power plants were designed to satisfy mainly the energy demand of Turin. To extend the methodology to other municipalities, a collaboration with the utilities is suggested to increase the representation of the supply side, as done with this paper for the demand side.

As shown by this paper, a discretization of the urban demand through the identification and simulation of reference buildings is a valuable contribution to improving the understanding of building retrofit potential, the reference buildings approach being useful to identify an average behavior for the residential sector. Despite this, in the future, with growing data availability thanks to the spread of digitalization technologies, data-driven approaches might be more suitable for this purpose, overcoming barriers related to RBs applied to large-scale analyses, such as catching shading profiles of closed buildings, internal loads, and infiltration rates, as explained in [43].

Further improvements in the methodology can be related to improving the representation of the influence that the DH network itself has on the heat demand. Delay effect and heat loss, together with mixing effects due to return flows of each building, comport a heat load profile of thermal plants different from that of buildings, especially from the peak load, which is different for magnitude (lower than user peak) and for duration (peak of thermal plant lasts for hours, for buildings lasts for few minutes). For a better demand and supply relationship evaluation, a future development of the methodology could integrate a tool to simulate the network to analyze load profile of thermal plant and to apply regulation efficiency intervention in building (as the anticipation of the thermal request of buildings to reduce morning peak analyzed in [57]).

Additional improvements in future analysis can be done by integrating the effectiveness of buildings savings related to the increase of temperatures (e.g., lower heating degree days might reduce the costs benefits related to energy retrofit, reducing its profitability) [46].

## 6. Conclusions

The aim of the proposed approach was to investigate the relation between buildings' energy savings and low-carbon heat generation strategies at an urban scale, to help municipalities to lead the transition towards a decarbonized energy society through a targeted planning of future investment and energy policies. For the achievement of the European goals in terms of CO<sub>2</sub> emission reduction and

primary energy consumption reduction, it is important correlate a demand reduction with a low-carbon supply strategy. The correlation of these two aspects is evident in the residential sector, especially in the historical buildings and general old buildings that represent the highest share of the residential sector in European cities. For these buildings, where the installation of new technologies, such as decentralized heat pumps, is difficult (due to either social, economic, and technical reasons), the role of the district heating, thanks to its easy integration with several low carbon technologies, is very relevant to pursue the goals of the energy transition. The proposed methodology allows an in-depth analysis on effective measures applicable for heat saving at the building level, integrated with an analysis of the energy system supply performed with the EnergyPLAN tool. The integration and expansion of DH in the city was analyzed through different hypothesis of future energy system configurations. The results underline the correlation between the demand side and the supply side, showing that a joint effect of both demand reduction at building level and change in the heat supply is needed to achieve the energy savings goals. Scenarios with changes in heat production provide a big reduction on CO<sub>2</sub> and TPES, due to the integration of heat pumps, and on biomass CHP. In particular ADV scenarios, with the integration of 250 MW heat pumps, 560 MW of heat storage, and 106 MW of biomass CHP comport a CO<sub>2</sub> reduction from a minimum of 56% (without considering buildings savings and DH expansion) to a maximum of 76% considering advanced renovation level for building retrofit together with DH expansion. The integration of large-scale heat pumps in district heating provides a strong reduction in natural gas consumption, and a lower dependence on natural gas assures a safe energy system. New investments in district heating and in building stock are supported by the strong decrease of fuel consumption and its relative costs. However, the cost reduction of these scenarios is supported by a presumed increase in the cost of fossil fuel and in the carbon taxes on 2050. The cost-effectiveness of the energy savings investment is strongly related to the trend of future energy policy decisions that can provide a strong push for embrace a low carbon energy system.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Average costs of building retrofit.

	AB 1945–1960	AB 1961–1975	AB 1976–1990	Average
WS (€/m <sup>3</sup> )	10.68	9.96	5.12	8.59
SR (€/m <sup>3</sup> )	34.23	34.35	25.61	31.40
AR (€/m <sup>3</sup> )	46.27	46.01	35.09	42.46

**Table A2.** Total cost of energy savings measures for volumes connected to DH.

	Average (€/m <sup>3</sup> )	Volumes DHMm <sup>3</sup>	Total Cost (M€)
WS	8.59	30.7	263.62
SR	31.40	30.7	963.6
AR	42.46	30.7	1303.38

**Table A3.** Investment and fixed operations and maintenance (O&M) [24].

	Investment Cost (M€)	Period (Years)	Fixed O&M (%)
Small CHP units	0.85	25	3.75
Heat storage CHP	3	20	0.7
Large-scale heat pump	1.7	25	0.9
Boilers (CHP)	0.12	20	3.8
Boilers (residential)/1000 units	12	25	3.8

**Table A4.** Fuel costs in the year 2017 [21].

	Natural Gas (€/GJ)	Biomass (€/GJ)
Fuel price	6	5.65
Fuel handling costs (distribution and refinery):		
To dec CHP, DH, and industry	2.05	1186
To individual house holds	3146	-

**Table A5.** Additional costs [24].

	Period (Years)	O&M (%)	Investment (€/KW)	Total Investment (M€)
Existing DH pipes + heat exchanger	40	100	10.20	5.92
New DH pipes + heat exchanger	40	1	1018.40	WS: 30.54 SR: 292.45 AR:292.45
Heat saving retrofit	30	-	-	WS: 263.62 SR: 963.6 AR: 1303.38

**Table A6.** Fuel costs 2017–2050 [21].

	2017	2050
Fuel price (€/GJ)		
Natural gas	6	11.83
Biomass	5.65	8.1
CO <sub>2</sub> (€/tCO <sub>2</sub> )	6	25

## Appendix B

**Table A7.** Geometric and construction data, apartment building 1945–1960 [36].

AB, 1945–1960			
Geometric Data			
Parameter	Symbol	Unit	
Gross heated volume	V	m <sup>3</sup>	5949
Net floor area	A <sub>n</sub>	m <sup>2</sup>	1763
Shape factor	S/V	m <sup>-1</sup>	0.46
N° apartments	-	-	24
N° floors	-	-	4
Gross heated surface	S	m <sup>2</sup>	2746
Gross heated floor	A <sub>1</sub>	m <sup>2</sup>	1595
Windows area	W	m <sup>2</sup>	217
Reference floor area	A <sub>ref</sub>	m <sup>2</sup>	1478

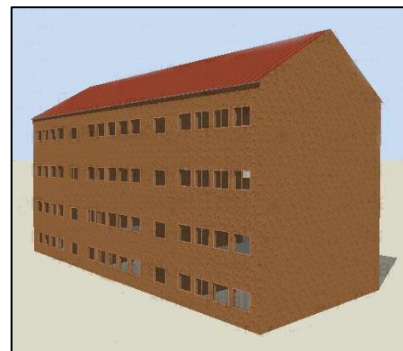


Table A7. Cont.

AB, 1945–1960			
Construction Data			
Roof	U	W/m <sup>2</sup> K	1.8
Walls	U <sub>1</sub>	W/m <sup>2</sup> K	1.15
	U <sub>2</sub>	W/m <sup>2</sup> K	2.6
Lower floor	U	W/m <sup>2</sup> K	1.65
Upper floor	U	W/m <sup>2</sup> K	1.3
Window	U	W/m <sup>2</sup> K	4.9
	g <sub>gl</sub>	-	0.85

Space heating profile

Table A8. Geometric and construction data, apartment building 1961–1975 [36].

AB, 1961–1975			
Geometric Data			
Parameter	Symbol	Unit	
Gross heated volume	V	m <sup>3</sup>	9438
Net floor area	A <sub>n</sub>	m <sup>2</sup>	2869
Shape factor	S/V	m <sup>-1</sup>	0.46
N° apartments	-	-	40
N° floors	-	-	8
Gross heated surface	S	m <sup>2</sup>	4346
Gross heated floor	A <sub>1</sub>	m <sup>2</sup>	2483
Windows area	W	m <sup>2</sup>	321
Reference floor area	A <sub>ref</sub>	m <sup>2</sup>	2159


Space heating profile

Construction Data			
Roof	U	W/m <sup>2</sup> K	2.2
Walls	U <sub>1</sub>	W/m <sup>2</sup> K	1.1
	U <sub>2</sub>	W/m <sup>2</sup> K	1.13
Lower floor	U	W/m <sup>2</sup> K	1.65
Upper floor	U	W/m <sup>2</sup> K	1.56
Window	U	W/m <sup>2</sup> K	4.9
	g <sub>gl</sub>	-	0.85

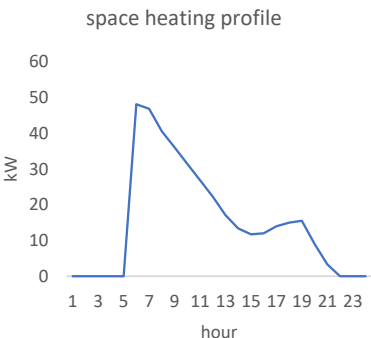
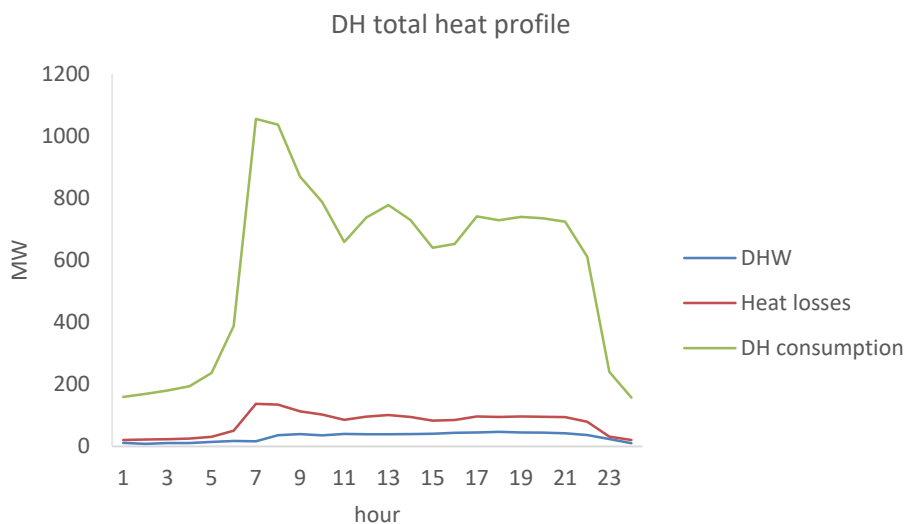
Space heating profile

**Table A9.** Geometric and construction data, apartment building 1976–1990 [36].

AB, 1976–1990				
Geometric Data				
Parameter	Symbol	Unit		
Gross heated volume	V	m <sup>3</sup>		
Net floor area	A <sub>n</sub>	m <sup>2</sup>	4123	
Shape factor	S/V	m <sup>-1</sup>	0.37	
N° apartments	-	-	48	
N° floors	-	-	6	
Gross heated surface	S	m <sup>2</sup>	4734	
Gross heated floor	A <sub>1</sub>	m <sup>2</sup>	3803	
Windows area	W	m <sup>2</sup>	361	
Reference floor area	A <sub>ref</sub>	m <sup>2</sup>	3474	

Construction Data				
Roof	U	W/m <sup>2</sup> K	1.85	
Walls	U <sub>1</sub>	W/m <sup>2</sup> K	0.76	
	U <sub>2</sub>	W/m <sup>2</sup> K	0.76	
Lower floor	U	W/m <sup>2</sup> K	0.97	
Upper floor	U	W/m <sup>2</sup> K	0.98	
Window	U	W/m <sup>2</sup> K	3.7	
	g <sub>gl</sub>	-	0.75	

**Figure A1.** Heat load profile: losses, domestic hot water (DHW), and heat consumption demand for district heating.

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## Article

# New Energy Policy Directions in the European Union Developing the Concept of Smart Cities

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**Abstract:** In the context of the European Union promoting clean energy, sustainability and better living conditions for its citizens, the development of smart cities is an initiative supported at the European Union level, in line with the new energy policies of the European Union promoted by the package “Clean Energy for All Europeans”. The concept of smart cities gains increasing importance in the European Union, a fact that is reflected in the project “European Innovation Partnership on Smart Cities and Communities” of the European Commission. Smart cities are a practical example of how the new energy policies shape the lives of the European Union citizens, trying to improve it. As a consequence, new business models arise in big cities, involving the use of technology for better living conditions. These new, technology-based business models are important, as they improve the life quality of the inhabitants, they reduce the climate change impact, and they contribute as well to job creation in the IT-industry, promoting innovation. They have as well a social impact, as they bring experts from energy policies, business, economics, legal and IT together in order to project a new type of city—the smart city. The research hypothesis of the present article is that there is a high acceptance towards the concept of smart cities at the European Union level and that this concept could be implemented with the help of information technology and of artificial intelligence. This way, legal provisions, economic measures and IT-tools work together in order to create synergy effects for better life quality of the citizens of the European Union. The research hypothesis is analyzed by means of the questionnaire as a qualitative research method and is as well assessed by using case studies (e.g., Austria, Finland, Romania). The novelty of the case studies is that the development of smart cities is analyzed due to the new trend towards sustainability in two countries with different living conditions in the European Union.



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## 1. Introduction

Smart cities are a concept of great importance due to their dynamics in our current society, a concept aiming to enhance sustainability. Cities tend to develop, and at the same time, the standard of living of their inhabitants develops, so new solutions must be found in order to harmonize these two trends. More than 55% of our planet’s population live in big cities, and the trend is ascending, according to the United Nations [1]

Europe will concentrate on a high degree of this urban development so that cities in Europe face new challenges related to the ascending trend of urbanization. Such challenges are related to modern buildings, to a modern, information technology-based public transportation system and to the increased use of clean energy in order to reduce the negative impact of urbanization on the environment. Big cities are important energy consumers, as 80% of the energy consumption in the European Union will be registered in big cities and their surroundings [2]. A consequence will be a high concentration of CO<sub>2</sub> emissions in

this area and thus a negative impact on the environment if new innovative solutions would not be put in place. In this context, it is important to shape energy policies at the European Union level, aiming for sustainability in big cities and promoting the smooth transition from big cities to sustainable smart cities. New energy policies are drafted at the present moment with a special focus on sustainability. They need as well to be operationalized to find a concrete expression and new projects in society implementing these new policy measures. Smart cities may be a concrete expression of the new directions of energy policies at the European Union in line with the principles of sustainability, a concrete expression of sustainability that was not researched enough until now, especially with regard to its social impact.

The aim of this paper is to assess new energy policy directions promoting smart cities and sustainability in urban areas, evaluating as well the acceptance towards these new developments and new tools in order to implement the business models in smart cities, such as artificial intelligence-based instruments. The research hypothesis of the present article is that there is a high acceptance towards the concept of smart cities at the European Union level. The evaluation of new energy policies in the European Union is important and needed, as the European Union has a very ambitious and visionary goal of transforming the European energy system into one of the most sustainable in the world.

In order to accomplish this ambitious policy goal, energy savings are needed, and energy performance must be increased. Such developments are supported by new IT&C technologies (used for smart metering and smart grid), by the Internet of things (IoT), by artificial intelligence and by raising the awareness at the level of the consumers and thus shaping new consumer behavior in this direction. Increasing the efficiency of buildings and raising awareness of consumers towards this issue is important. A document establishing such concepts and developments and thus relevant for the assessment is the Energy Performance of Buildings Directive (EPBD). It is in line with the initiative of the European Commission to increase their energy efficiency as part of its new energy policy [3]. Buildings are important energy consumers in cities of the European Union, and the building sector is responsible for 40% of the total energy consumption and for 36% of CO<sub>2</sub> emissions [4]. Given these circumstances, the EPBD Directive expresses the need to find solutions for the construction of zero energy buildings by 2020 [4]. All buildings that are built should be zero energy with no carbon emissions in order to achieve the ambitious policy goal mentioned above.

These policy measures should be supported by innovative technologies (such as IoT and artificial intelligence), which are described in the Strategic Energy Technology Plan (SET Plan), making it possible to ensure a transition to a low carbon economy by 2050 in the European Union. This objective was mentioned in 2011 in a document of the European Commission, namely in the Roadmap for moving to a competitive low-carbon economy by 2050. The documents mention as well the concept of smart cities, reflected in the Smart Cities and Communities Initiative of the European Commission. The aim of this initiative is to ensure cooperation between stakeholders for reaching an improved standard of living in smart cities in the European Union and thus improving the life quality of citizens in the European Union [5]. Energy-efficient cities are part of the Europe Strategy 20–20–20, and their development can be ensured by using IT&C technologies and artificial intelligence supporting new business models for these cities and their inhabitants. In the context of digitalization and of the increased use of information technology in order to improve our lives, artificial intelligence is a good tool to be used for improving smart cities if there is acceptance of this new instrument. The use of artificial intelligence may encourage the development of new product markets in smart cities, such as the market for smart homes or the market for smart vehicles, an issue which is assessed in the present research. All these new aspects related to new markets and products are a consequence of implementing the concept of smart cities in the European Union.

The methodology of the present research is based on a qualitative research approach, with an international, comparative dimension. Case studies, the questionnaire used as a

qualitative method and a review of the relevant literature are used as research methods for the present article.

The present article has the following structure for approaching the research topic: Introduction, The current state of research (Literature review), Materials and Methods, Results, Discussions, Conclusions and References.

## **2. The Current State of Research (Literature Review)**

### *2.1. Smart Cities—Using the Benefits of Technology*

According to the studied literature, a smart city is a place where the traditional networks and services are made more efficient by using digital and telecommunication technologies, for the benefit of its inhabitants and businesses [6]. A smart city is thus a sustainable and efficient urban center that provides a high quality of life to its inhabitants through optimal management of its resources.

According to the literature, information technology (IT) comprises “means and methods of collecting, processing and transferring data” [7].

### *2.2. Smart Cities and Sustainability*

Smart cities are a concrete expression of implementing sustainability. Sustainability is a concept that does not have a unitary approach in the economic literature. Despite the difficulty of finding a unitary definition, it was clear that sustainability and sustainable development are important goals for international organizations (United Nations, 2015). Even with no universal definition of sustainability [8], it is clear and commonly accepted that this concept addresses human needs from a broad perspective [9]. Sustainable development can be understood in its environmental dimension, in its economic dimension and in its social dimension [10]. Given the challenges of climate change, the environmental dimension is currently more often analyzed. Nevertheless, the social dimension of sustainability is as well of great importance due to its impact on society [9].

The present research analyses smart cities in the context of new, sustainable energy policies, building a bridge between previous literature and the newest developments at the European policy level. It considers the consumer focus in the transition towards new energy policies [11], aspects that have an impact in improving smart cities. The new sustainability-based energy policy is determined by consumer preferences [12]. Given the current trends of analysis of circular economy [13] and of its impact on our society, the present article is in line with previous research, further developing it and adding a new perspective of the European policies. The research has a multidisciplinary dimension that is appropriate to the research question, as Economics belongs to the field of econosciences [14], which allows this kind of approach.

## **3. Materials and Methods**

The present article uses an interdisciplinary research approach, assessing aspects of business, economics, legal provisions and social impact in order to provide a comparative perspective with an international dimension on the researched topic. The research hypothesis of the present paper defines smart cities as a visionary concept supporting sustainability as a mindset of the future citizens.

The relevant literature was consulted with regard to the researched topic. The definitions of the relevant concepts and their importance were summarized in the literature review.

The questionnaire is used as a qualitative research method. The questionnaire contains five sections summing up 21 semi-structured questions referring to the topic of new energy policies in the European Union and their application in order to achieve sustainability in its economic, social and environmental dimensions. The questionnaire contains questions analyzing the acceptance of these new values within the citizens of the European Union. The research hypothesis of the present article, which is the research problem if there is a high acceptance towards the concept of smart cities at the European Union level and if that this concept could be implemented with the help of information technology and

of artificial intelligence, is being assessed in the results of the questionnaire. The type of questions corresponds to the semi-structured interview. The questions offer the respondent the opportunity to add some ideas or express his/her opinion if this is not contained in the response alternative in the questionnaire. As an example of a question, the respondents are asked about how they assess the orientation policy of smart cities towards clean energy, energy efficiency, smart vehicles or consumer protection. The research is based as well on questions assessing in detail the acceptance of specific elements, which are the basic aspects of smart cities. This acceptance is detailed in separate questions in the questionnaire about the importance of the reduction of carbon emissions, the importance of energy efficiency, of energy savings and recycling (and thus promoting a circular economy), to the importance of environment protection, to the importance of Clean Energy and renewable energy.

The type of analysis used in the present research for assessing the interviews is the thematic analysis. The answers of the respondents were grouped by means of the thematic analysis in order to have a better overview of the expressed ideas and to better follow the reflection of the research hypothesis in the answers of the respondents. This research design ensures an optimal valuation of the expertise of the respondents. Ideas regarding the acceptance of smart cities in the European Union, the need to focus on energy savings and circular economy, the need to improve life quality, the importance of the use of technology and the need to improve mobility were assessed in a comparative manner. Evidence from the interviews supports the formulated research hypothesis. The research was conducted in the period February 2018–February 2019, assessing the answers of 138 respondents. The respondents to the questions are representatives from companies acting in the energy sector in the European Union (from countries like Romania, Austria, Germany, the United Kingdom, Italy, Portugal, Spain, Greece, Belgium), university professors from the European universities from Romania, Germany, Poland and Bulgaria, with a high academic qualification. The experience and qualifications of the respondents were used in a qualitative research approach. The criteria for selecting the respondents were their experience in fields that are relevant for smart cities, such as the field of energy or new developments in the energy sector. The respondents are active as university staff involved in teaching subjects related to energy, or they are representatives of companies in this field, acting at the top management level.

Using qualitative methods in economic research is an aspect of novelty and of originality, corresponding to the newest trends in academic research in the field of business and economics. Qualitative research empowers the researcher at gives a high role to the research participants in being part of the research project. This is a motivation for the research participants, e.g., the respondents, to participate in the research project, as they are aware that their qualification and expertise becomes useful for research. This is the reason why special importance was given to this research method in the present article.

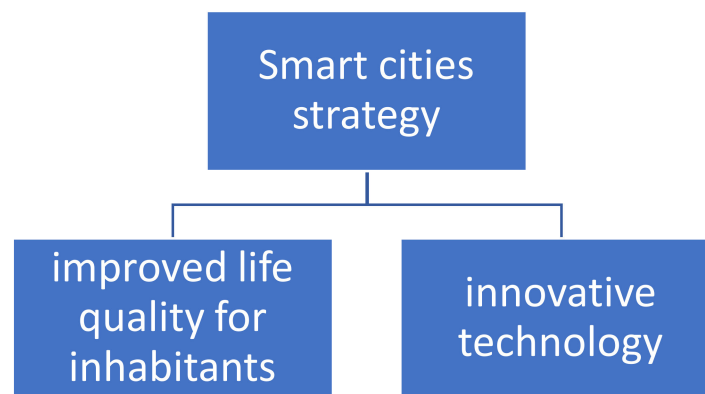
Another research method used in the present article is represented by case studies from Austria and Romania presented in a comparative manner. Vienna was chosen as a case study, as it offers a very high standard of living, a very good quality of life according to international rankings. For illustrating current developments in Romania in this field, the city of Cluj-Napoca is presented as a case study. Smart cities find a great acceptance in Romania and are an opportunity to improve the life quality of inhabitants, a trend that is appreciated in Romania and which offers as well the opportunity to innovate for entrepreneurs and firms (startups) wanting to support this modern and sustainable trend.

Indicators provided by the European Commission are analyzed in a complementary manner, in a mixed-methods approach. Such as indicator is the circular economy Indicator, showing to what extent the mindset of people in the European Union changed in this field and how the awareness regarding the importance of sustainability resulted in societal behavior.



#### 4. Results

Sustainable business models are a key concept for creating smart cities. Such cities should offer a high quality of life by using IT&C based solutions in smart cities. Based on advanced algorithm and control techniques, Computational Intelligence and machine learning will enable us to think about new optimization levels for the energy systems in a smart city. The new communication technologies and the related communication networks and connectivity must be followed by a new cyber-security design for energy systems in a smart city [15]. Supervisory control and data acquisitions (SCADA) systems will be confronted with new high-level processes for the supervisory management. New security policies for smart cities will as well include the concept of a safe city [16]). The two pillars of improving smart cities are represented in Figure 1.



**Figure 1.** Pillars for improving smart cities. Source: own representation based on own research, including [15].

The research hypothesis of the present paper defining smart cities as a visionary concept supporting sustainability as a mindset of the future citizens is validated by the research results. Both pillars have similar importance in the vision of the respondents, as 55% of the respondents indicated improved life quality as the main element of smart cities strategy, while 45% of the respondents referred to the importance of innovative technologies in supporting smart cities. Especially people working in the private sector with age under 40 years found the importance of technology very high. Among the respondents, IT-workers were as well interviewed (about 3% of the interviewed respondents), and they found artificial intelligence of very high importance in the development of smart cities. An important research result is that respondents in the IT-sector showed great awareness towards the importance of clean energy and of new energy policies.

Improved life quality becomes a mindset of the European Union citizens. They look for the proper instruments to implement sustainability-based energy policies, which become concrete in the concept of smart cities.

At the level of the European Union, Eurostat presented the Urban Audit for EU countries as a monitoring framework for sustainability aspects. This tool is based on Eurostat data from yearbooks, and it is compiled with the help of national statistics offices. This tool is appropriate for assessing smart cities in the European Union, as it is a Eurostat tool, and therefore, we are not confronted with the problem of the lack of comparable data or of a unitary methodology any more [9]).

Vienna, the capital of Austria, accomplishes the goals of smart cities, as a good quality of life to its inhabitants, achieving as well to save resources and to use modern and innovative technologies. Vienna defines as goals until 2050 the efficient use of energy, good energy performance for its buildings, good mobility achieved with effective use of resources [17]. The attributes of the smart city Vienna are represented in Figure 2: Attributes of the smart city Vienna.

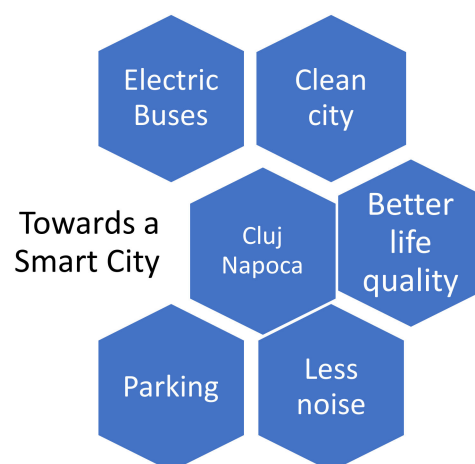


**Figure 2.** Attributes of the smart city Vienna. Source: own research based on [17].

Life quality is a main goal in the long-run in developing smart cities, as is obvious in the case study of Vienna. This goal may be supported by technology, which is a tool in implementing the new directions of sustainable energy policies. Given this fact and the importance of technologies in implementing the concept of smart cities, new business models related to this concept may be implemented by means of information technology and of artificial intelligence. 55% of the respondents to the questionnaire found life quality as the main goal to be achieved in smart cities. 30% of the respondents found technology very important, while 15% were preoccupied with energy savings in their environment. The city of Vienna was selected for this case study, as it is recognized for urban development, with experts researching this field [18].

Another example of a smart city in Austria in Graz, where energy efficiency is an important aspect of improving life quality in this city [19]. “smart city Project Graz” is a project implementing this concept [20].

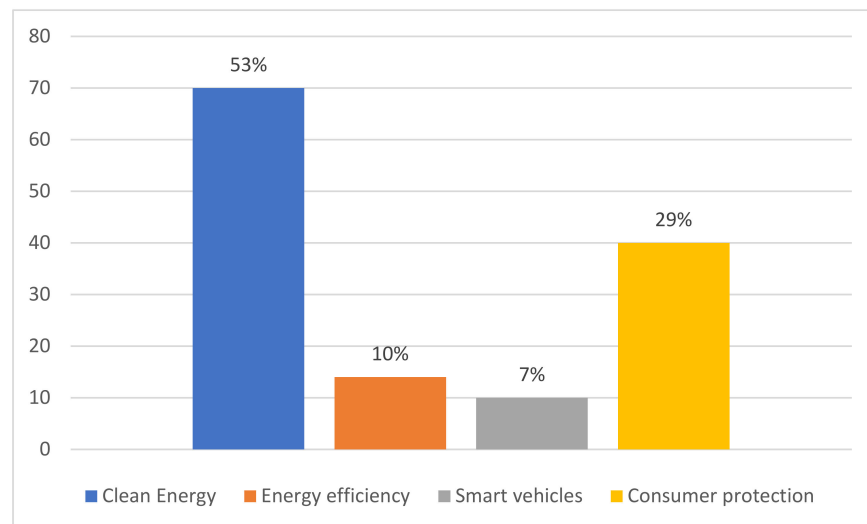
In Romania, the trend of promoting smart cities finds acceptance. A city with an impressive development in this direction is Cluj-Napoca. It has built a public transportation system based on clean vehicles, such as electric buses, and is supported by technology in order to provide information to the inhabitants of the city. It tries as well to reduce noise pollution and to provide smart parking for its inhabitants. Its main features are represented in Figure 3.



**Figure 3.** Development of smart cities in Romania: Cluj-Napoca. Source: own research based on [21].

Another city in Romania trying to become a smart city is Oradea, which implements criteria like building a Smart Community based on smart infrastructure and smart mobility, smart utilities, smart environment, smart living and as well smart government in order to support the digitalization of the local administration [22].

The present research analyzes the opinion of experts from various countries related to the topic of smart cities. There are specific semi-structured questions in the questionnaire aiming to investigate the acceptance of the respondents towards the new values of sustainable energy policies, which are implemented and get concrete expression in the development of smart cities. Such values are related to the acceptance of clean energy, of defining life quality depending on sustainable development aspects, the willingness to implement these new concepts in daily life and the need to have new energy policies considering the new trends of sustainability. The assessment of the questionnaire results pointed out a high degree of acceptance towards promoting smart cities in the context of new energy policies of the European Union. The acceptance towards the values promoted as goals of smart cities among the interview participants is illustrated in Figure 4.



**Figure 4.** Acceptance towards smart cities. Source: own conducted research.

An important difference between Austria and Romania related to the smart city strategy is given by the fact that Austria has a well-established, long-term strategy for smart cities and establishes its goal for the smart city strategy until 2050, while in Romania, there is not yet such a long vision regarding this aspect. The idea of smart cities is only at the level of pilot projects in Romania, and there is no clear framework yet, how this field would develop.

The results of the own conducted research by using the questionnaire revealed the fact that more than 50% (53%) of the respondents (74 respondents of 138) believe that clean energy is a key-direction of new energy policies.

One of the main goals of promoting new energy policies is related to consumer protection; however, as the research results indicate that 29% of respondents find this goal important.

Energy efficiency is an important energy policy goal at the EU level. Unfortunately, this goal is not very clear or not so important for the majority of the consumers. Therefore, only 10% of respondents consider that energy efficiency must be a priority for sustainable development. Another curious result is that only 7% of respondents find smart vehicles as new instruments to promote new energy policies. It must be mentioned that the results are significantly influenced by the different living conditions in different countries in the EU (e.g., Austria and Romania).

An important index that might reflect societal behavior in the field of energy policies is the circular economy indicator, which is provided by the European Commission. Figure 5 is presenting a comparative view among the values of this indicator in the European Union Member States:

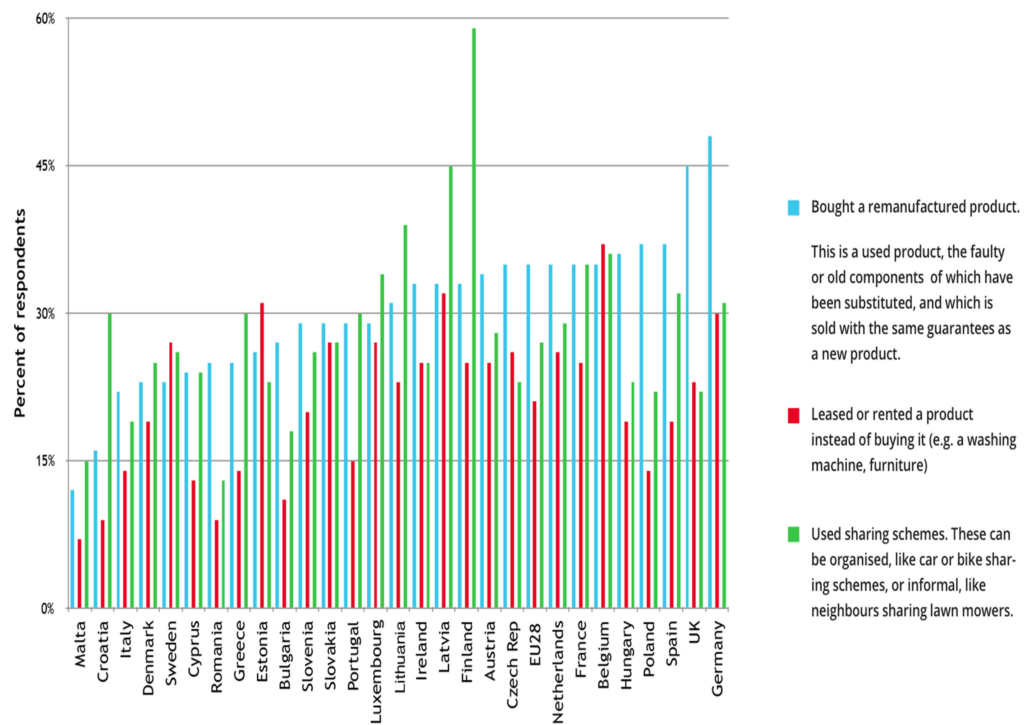


Figure 5. Circular economy indicators in the European Union. Source: [23].

This indicator shows societal behavior related to the circular economy, meaning if there is a common practice related to the circular economy in order to protect the environment like we have the case in Austria, or it shows if there is a lack in such behavior like we have the situation in Romania for example. In such a situation, an awareness raising campaign is needed in order to draw attention to the importance of this topic.

A more detailed comparative perspective (at the global level) related to the electronic media, which is an important sector in the European Union, is provided by the European Commission in Figure 6.

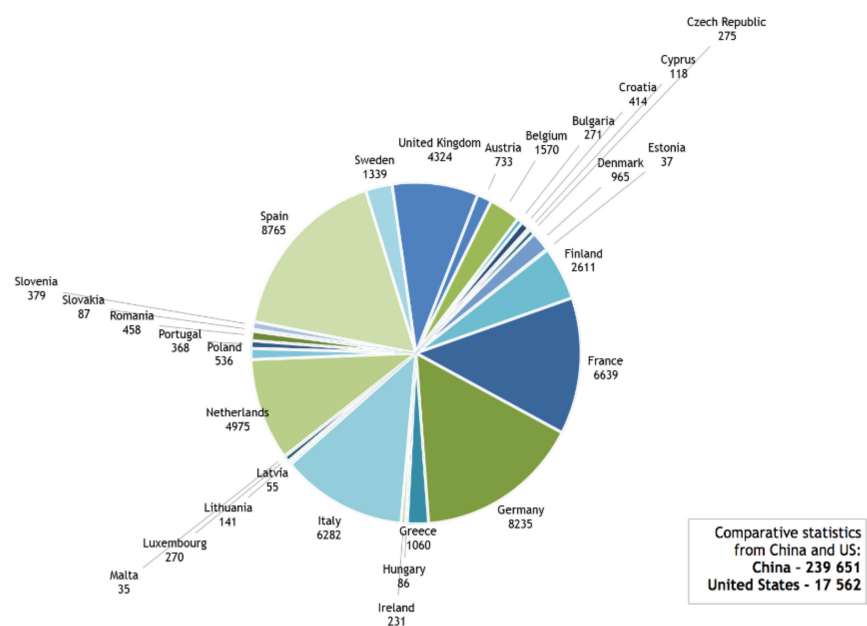


Figure 6. Circular economy in electronic mass media. Source: [24]

Smart cities manage to gather the best ideas and innovation in order to protect both consumers, which are inhabitants of smart cities and the environment. A sustainable approach is needed in the context of providing better health to the inhabitants of big cities. Such aspects are as well a result of a shift in cultural values. People share values related to sustainability and to sustainable approaches, taking into account future generations. Improving smart cities is a topic bringing together the best experts in business, economics, in the legal field, in technology and in social research for evaluating the impact of these cities in society.

## 5. Discussions

Discussions related to the research topic might refer to the fact that there is no unitary definition of smart cities at the European Union level, meaning there is not only one acceptance of this concept. Being a new concept, it is still very dynamic and fluid, and it is being shaped according to the latest developments at the international level. Given the lack of a unitary, unique definition of the concept of smart cities, it is difficult to find a harmonized approach, which is valid in each and every country.

### 5.1. A Comparison of the Findings with Previous Research

Application programming interfaces (APIs) for smart cities can be developed in order to implement digitalization in cities for the benefit of the consumers. Such applications have already been used in smart cities in Finland. More than that, in Finland, the approach is to have harmonized applications for smart cities. This ensures comparable data support that can be used for improving the life quality of the citizens in smart cities [25]. The best practices in Finland in cities such as Helsinki, but as well in Tampere, Espoo and Turku are a good example of using technology in the best interest of the consumer, of the citizens [26]. The impact of technological development is thus revealed not only in the technology sector but as well in the whole society. Positive externalities can thus be achieved, with important social benefits and with social value.

### 5.2. Theoretical and Practical Implications of the Research

At the same time, a common, harmonized basis could be established if this concept of applications for smart cities find acceptance. It could be discussed if best practices showing the advantages of these technology tools might be used as a source of inspiration for some other smart cities in the European Union, needing guidance in order to implement the concept of smart cities. The City of Barcelona in Spain is another example of a smart city using applications for smart cities in order to provide data for companies and municipalities or other institutions, making better cooperation between these actors possible and promoting the use of digitalization for improving life quality [17,27]. (Projects at the European Union level are developed in order to implement the concept of application programming interfaces for smart cities. Examples of such projects developed at the European Union level are the projects FI-WARE, ICOS (Intelligent/Smart cities Open-source community) and smart objects for intelligent applications (SOFIA) [17,27]. The concept has a real success as well beyond Europe, for example, in the United States of America, with New York as a best-practice example [17]. These positive experiences proved the fact that it is a successful concept, and countries such as Romania, which intend to develop the concept of smart cities at their level, may use such positive experiences as best practice.

### 5.3. Limitations of the Research

Possible limitations of the research could be given by the fact that the research is performed on a qualitative basis, not a quantitative one. Another limitation is the fact that the case-studies-approach covers only specific cases; it cannot be expanded on each and every city. Each city has a different practical situation and different policies or criteria for defining smart cities.

Another possible limitation of research could be the lack of comparable data, as the field of smart cities is new, and there it is difficult to find harmonized, comparable data in this field.

#### *5.4. Conclusions and Future Perspective of the Research*

Another topic of discussion might be if it is measurable if a city is a smart city or not if it accomplishes the status of a smart city if there are any objective, measurable criteria for establishing if a city is a smart city or not and if there is general acceptance at the European Union level or at a global level regarding the assessment of smart cities and of cities aiming to become smart cities.

The discussion might be developed as well around the idea that not only it lacks a common, unitary definition of smart cities worldwide or at the European Union level, there is, in fact, no unitary definition of sustainability worldwide. Given the complexity of this issue, discussions may clarify what is, in fact, the sustainability of smart cities, how it can be evaluated to what extent a smart city is sustainable, to what extent it contributes to a sustainable environment if there are any measurable criteria or indicators to answer these questions and as well if there is acceptance towards the use of some indicators in this field.

## **6. Conclusions**

The research findings of the present article validate the research hypothesis that smart cities are a visionary concept supporting sustainability as a mindset of the future citizens. New business models related to this concept might be implemented by means of information technology and of artificial intelligence.

These tools may contribute to a better future for all the inhabitants of smart cities and might have a social impact in improving the quality of life of people living in smart cities. The gap between technology-based approaches and human-focused approaches might this way disappear, as the two visions can find solutions towards better living conditions. The use of information technology and artificial intelligence for smart cities has a very high potential, given the development of the IT sector worldwide.

The novelty and originality of the present research are given by the interdisciplinary research method used in order to evaluate new perspectives related to smart cities in the European Union, aiming to achieve sustainability and better life quality for citizens. The methods used have a contribution to research, as they use a comparative perspective with an international dimension, using the experience of the respondents in a qualitative manner. Case studies show best practice examples for the researched concept that can be used by new Member States such as Romania, having less experience with smart cities, but wanting to implement this concept.

The results of the present research can be further developed in future research projects. The findings of the present research will have an impact on future research articles, as the acceptance towards smart cities needs to be assessed before implementing measures related to the support and financing of smart cities. The acceptance of citizens towards these new measures needs as well to be assessed. Such additional research will for sure be needed in the future, given the impact novelty of the subject and the dynamics of smart cities in the European Union, a project aiming at better living conditions for people living in these cities. Given this context, it is a good opportunity to ensure collaboration between research and practice. This way, a strong impact of research beyond academia is achieved, an impact in the society contributing to improving the values and the standards of society and creating a new mindset in accordance with new, modern visions based on sustainability.



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Article

# Economic Framework of Smart and Integrated Urban Water Systems

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**Abstract:** Smart and integrated urban water systems have important roles in advancing smart cities, but their contributions go much further by supplying needed public services and connecting other sectors to meet sustainability goals. Achieving integration and gaining access to financing are obstacles to implementing smart water systems and both are implicit in the economic framework of smart cities. Problems in financing the start-up of smart water systems are reported often. The local and diverse nature of water systems is another barrier because an approach that works in one place may not work in another with different conditions. The paper identifies the challenges posed by the economic framework and provides examples from four cities with diverse characteristics. It outlines pathways to advance implementation of smart water systems by improving control strategies, advancing instrumentation and control technologies, and most of all, to help transform cities by raising customer awareness and trust through reliable and useful water information.

**Keywords:** urban water; smart systems; automation; integrated management



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## 1. Introduction

Smart cities have many interrelated parts, and their water systems provide essential functions by supplying needed public services and connecting other sectors with water to aid them in meeting economic, social, and ecological goals. To play these roles effectively, urban water systems should be integrated and take on smart attributes [1]. However, while technological aspects of smart urban water systems are impressive, the systems face challenges to achieve integration, employ smart technologies effectively, and sustain adequate financing sources [2].

Achieving integration and gaining access to adequate financing are principal obstacles to advancing the state of the art of smart urban water systems. While they provide multiple types of services to diverse stakeholders and are vital to cities, they confront financial challenges caused by their multiplexed economic framework. Managing these challenges is complex in cities with decentralized power structures, especially considering issues of affordability and financial limitations.

The paper describes the economic framework of smart water systems and smart cities, and it explains the resulting incentives and controls that it imposes on them. It also identifies challenges the systems face, and it outlines future directions to help advance the implementation of smart water systems in smart cities. The future directions go along three lines. One is improvement in control technologies, which is the main topic that is discussed by researchers studying smart water systems. A second is the advancement of instrumentation and controls, which is driven mainly by commercial incentives. Most significant, however, is the third line, which is about how customers use smart water information to help transform cities.

Several brief case studies of smart urban water systems and integrated approaches are summarized as examples of current situations. These were selected from a growing inventory of case studies that have been made available through recent studies of the

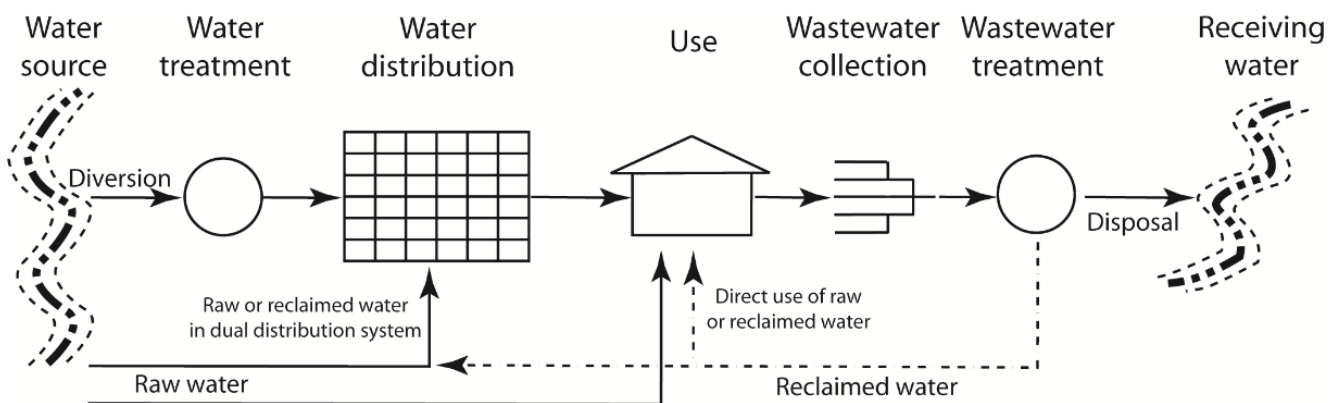
International Water Resources Association [2]. The selected cases illustrate a leading-edge city (Singapore), a new smart city in Korea (Paju), a growing medium city in the western United States (Fort Collins), and a large city in Mexico with a very limited water supply (Juarez). While the case citations are brief, they range across the major issues along the three lines of discussion, advancing technologies, new control methods, and customer interactions in urban areas.

Interest in smart water systems is advancing rapidly, but their implementation and success will be shaped more by economic and social forces than by advances in technology. The literature about smart water systems mainly focuses on examples of new technologies, and this paper aims to focus more directly on the economic forces that must be confronted by system managers to facilitate improved urban water services.

## 2. Urban Water Systems

Urban water systems are conglomerates of the infrastructures and operating controls of water supply, wastewater, stormwater, and recycled water systems [3]. They serve the social, constructed, and natural subsystems of living cities and they connect elements of these subsystems through interdependences [4]. For example, water supply connects to public safety by providing standby fire protection, stormwater systems can add to open space and recreational opportunities, and urban water systems draw supplies from ecosystems and can in turn nourish them.

This general perspective explains how water interacts with other subsystems, but a city is a system of systems, and it requires more information to explain how urban water systems work and are controlled. A concept for the interdependences among water supply, wastewater, and reclaimed elements is shown in Figure 1, and stormwater systems can be shown to cut across these as they involve entire cities. Stormwater harvesting can be added to the diagram, as well as the biosolids management that results from wastewater treatment.



**Figure 1.** The urban water system.

The urban water system works with raw water diverted and conveyed to treatment, distribution, and to users. Wastewater is collected, treated, and discharged to the receiving stream. Biosolids (or sludge) are dewatered, digested, and disposed of. The stormwater system traverses the city to convey diffused waters, some of which end up in the collection system. Water can be recycled from the wastewater or stormwater system, and raw water can be used directly for purposes such as fire suppression or landscape irrigation.

Integration of urban water systems requires cooperation among the management structures for the separate services. This can be formal, as in placing all services in a single organizational unit, or it can be informal, with cooperation occurring on an ad hoc basis. Formal integration requires a comprehensive approach that includes diversifying sources, protecting water at its source, and integrating operations for water storage, distribution, treatment, recycling, and disposal. This requires that the systems are operated as one utility to facilitate efficiencies like the recycling of wastewater or reducing water footprints.

Informal integration is much weaker and depends on incentives as well as opportunities for joint work [5].

As urban water systems are nested within the economic, social, and natural systems of cities there are several facets of integration. One integrates the services, such as when the separate services are operated as one utility. Another facet of integration is between the utilities and the external water environment of the streams and aquifers in and around the city. The urban water system impacts the interflows between ground and surface water and the heat island effects in cities, as well as flood plain health and urban ecology. A test for the effectiveness of integration is whether it enables the city to reach net-zero impact status in providing water, preventing pollution, and sustaining urban ecology.

### 3. Why Integration Is Needed

Integration among the separate urban water subsystems is a logical partner to smart systems. Application of controls to the separate water systems has been evolving for decades, but without integration, the efforts will fall short of addressing the major issues that cities face. This reality is widely recognized in the water industry and among urban leaders, and concepts such as One Water are emerging to develop appropriate strategies [6–8]. As an example, one of the cases cited here, the city of Singapore, faces the need to develop a total One Water approach if it is to meet its water needs in the future. Another of the cases, Juarez, which also faces a severely limited water supply, is addressing its smart water system with a different approach.

Integrated urban water resources management through the One Water approach has the potential to affect the shape and functionality of cities [9]. If the One Water approach is to achieve its goals, it must provide customers with integrated information to avoid confusion. For example, customers would not tolerate one message about water use and another about wastewater, especially when they are confronted with so many new categories of information in today's world. If integration can give people a sense of living in a total water environment, they will be more likely to accept a bill for services that pays for all systems involved. They should be informed how smart systems are improving efficiencies through combinations of services with multiple use facilities, for example, detention ponds and stormwater harvesting. Integration can improve information flow in different ways and, if handled effectively, has the potential to improve customer trust in utilities. Another important advantage of integrated approaches is to protect the urban water ecology, which can be built into the combined system to minimize water withdrawals and protect water quality and species [10,11].

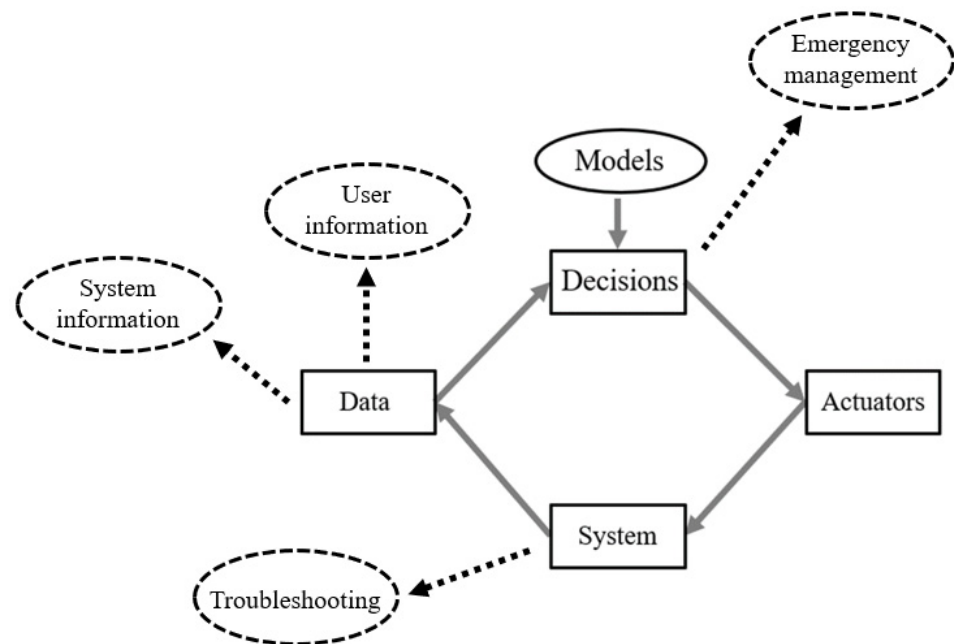
### 4. Smart Water Systems in Smart Cities

A smart urban water system would join the constellation of other smart systems in a smart city, which use computer controls and information to collect data, use that data to improve operations, and communicate with citizens about all aspects of their lives in the cities [12]. In a smart city, a smart integrated urban water system would feature infrastructure controls, collection of system and user information, application of the information to control water operations and to inform citizens, and it would be available for emergency management.

The concept is illustrated in Figure 2, which shows a system to be controlled and actuators to implement controls based on decisions informed by models and data. The data collection function informs system operators and users as well. Data from the system can be used for operations and troubleshooting. Emergency information can be sent to the actuators.

The concept has evolved from the early supervisory control and data acquisition (SCADA) and control systems to today's smart concept [13]. More specifically, prior to the evolution of smart systems, the concept would have not included the transmission of data shown by the dotted lines stemming from the general flow of information and control

commands. So, the ability of the smart system to provide the information for operations, customers, and emergency management comprises the most promising new feature.



**Figure 2.** Systems control and information interfaces.

These features of smart water systems have evolved from the past when information-based controls started with the advent of computers. This led to the development of the SCADA systems, and later sophisticated databases and geographical information systems were added to create technology-based platforms for system management. When personal digital assistants became available around the turn of the century, they were widely used in control and data acquisition functions.

Currently, these technologies have advanced with the development of smartphones, smart meters, and improved process controls [14]. Toward the future, more automation, advanced use of information for system management tasks such as leak detection, and more attention to cybersecurity are expected. Additionally, user information is expected to improve substantially.

### 5. Controls, Instruments, and Utilization of Smart Water Systems

The advancement of technologies for instrumentation and controls is driving the trend toward smart systems in different sectors of the economy. The concept of smart systems is being applied in cities, for example with smart buildings and smart transportation systems, among others. All have similar attributes based on the availability of sensors, actuators, and controls of subsystems for functions such as lighting, energy management, scheduling, and more.

Advancement in control methods follows the availability of technologies but also learning and experience about successful strategies. For example, in the case of smart water systems, some computer-based simulation models have proved to be useful and effective, while others have been developed but discarded due to lack of practical application. A possible example of this situation is the use of control methods that seem promising but have high levels of complexity and maintenance requirements that create a risk of malfunction. The use of inflatable dams placed inside of combined sewers to control overflows seems to fit this category [15]. These were proposed 50 years ago in San Francisco, for example, to address the expensive and perplexing problem of the aging combined sewers. However, their application has been limited.



While much of the interest in smart water systems has been driven by technologies and control methods, how customers use smart water information to help transform cities is more strategic. If the past is a guide to the future, it is expected that technologies and control methods will continue to advance incrementally, new business opportunities will be created, and experts and managers will continue to seek out new methods to experiment with them. Meanwhile, the benefits of these advances to customers and how the evolving smart systems are accepted and improve quality of life in cities remain larger questions. This issue is not limited to smart water systems, of course, because people today are confronted with a rapidly changing information environment which affects their daily lives in many ways.

## 6. Economic Framework of Smart Water Systems

An economic framework for smart water systems will involve the supply and demand for the public and private goods provided, their direct and indirect benefits and costs, and their linkages and impacts due to interdependences with other sectors. The organization of system management to facilitate collective action is also involved, as are social issues stemming from interactions with system customers and other stakeholders [16].

The demands for water, wastewater, stormwater, and recycled water services are different. The water supply and recycled water are commodities that can be sold like toll goods [17]. Most explanations of water sector demands focus on them, but the demands for other services must also be assessed. Wastewater service comprises carrying unwanted used water away from properties and requires paying a portion of the treatment and disposal. Stormwater service involves draining properties and public areas and paying to prevent pollution from urban runoff. The supply of each of these services involves a combination of responding to demands and meeting mandates.

The direct and indirect benefits and costs of the services stem from the demands that are to be met [18]. The benefits of water supply services involve applying the water for uses that range from meeting essential drinking water requirements to satisfying social needs, like health-related hygiene in the home. For wastewater, the direct benefit to customers is the removal of the unwanted residual water, and environmental protection is an indirect benefit. Stormwater services have multiple benefits, including protecting property and facilitating traffic movement in the city. Their multi-faceted attributes have made them a key part of a sustainability assessment protocol [19]. Taken together, the benefits from urban water services range across multiple categories and cannot be quantified easily.

The indirect benefits of urban water services demonstrate the connector roles of water services to various aspects of the economy and society. They stem from linkages and interdependencies with the other sectors, like employment, housing, energy supply, urban transportation, and the environment. Social impacts from water and its interactions can be considered indirect benefits and costs, and there is a substantial literature discussing how to define them [20].

Smart water systems will operate in the context of these interdependencies during normal and emergency times. For example, quality housing depends on meeting all water demands effectively during normal times. If there is a failure, the quality of the housing deteriorates. In the case of emergencies, the interdependencies can lead to systemic failures. For example, during flooding the failure of a stormwater system might trigger failure if the flooding shuts down a part of an electric power system [21].

The economic framework also involves the organization of urban water systems to facilitate effective operation and integration. The organization will depend on the structure of government and on public–private cooperation. Each of the services can be a separate utility or various degrees of consolidation and integration can be forged.

Finance is perhaps the most important issue in the economic framework of smart water systems. The management organizations can operate as utilities, but public goods are included among their services, and financing them may require subsidies along with fees for services. Each of the water services has its own financial structure. For example,

water supply is like a public utility. Wastewater involves charges that are mandatory and may be offered like a utility, even if its services do not involve the distribution of a commodity. Stormwater has a unique financial structure and has been moving toward a utility model [22]. Recycled water is difficult to finance but is positioned as a utility to facilitate it [23].

By adding smart capabilities to integrated urban water systems new possibilities for effectiveness, equity, and reliability are created. Perhaps the greatest benefits are to fulfill demands more effectively and to extend services on a cost-effective basis to more people. Smart systems with their information and computing technologies should be able to promote integration through linkages for communication and controls [24]. By sensing the status of systems and their performance, greater reliability should be fostered [25].

In the category of improving performance by reducing failures, smart systems can monitor environmental water quality and water in piped systems to prevent exposure of people to negative situations [26]. Additionally, hydrometeorological sensing networks can provide advance notice of urban flood problems and warnings can be issued [27]. Blocking cyber terrorism is another potential benefit, although the smart capability added by linking the systems may open them to new possibilities for attack [28].

Urban customers can expect more information about total benefits from water services and they can learn more about the total picture of water in cities through education programs. They can also learn about water finance and conservation with information about their bills. Subject to privacy concerns, information can be extended down to the water use of individual fixtures by using the technology of the Internet of Things (IoT).

## 7. Examples of Smart Integrated Water Systems

The selection of brief case studies as examples is based on innovation and illustrates a range of situations. Singapore is one of the world's major cities, and it is chosen as the primary case study because it has developed its concepts comprehensively over a period of years. Paju Smart Water City in South Korea is smaller than Singapore and its experience is explained due to its connection with an evolving smart city. Fort Collins, Colorado is still smaller and considered a medium city in the United States that is evolving its smart systems in ways that are characteristic of leading-edge cities. Juarez, Mexico is a large city in an arid zone with major issues in sustaining an adequate water supply. It has used smart systems to address major issues of sustainability.

In Singapore, the imminent loss of its source of water motivated the city to create an integrated water system, and this led to the development of a "four taps" approach to water management that includes local catchments, imported water, reuse, and desalination. The four taps provide for integration of sources, reuse provides a link between water supply and wastewater infrastructure, and a separate stormwater system is also used [29].

Singapore's water agency (PUB) has explained its approach to smart water management [30]. The integration will connect the smart drainage grid, smart plants, smart water grid, and smart sewer grid. Technologies to enable the smart features will include machine learning for decision support systems, big data to provide insights about the system, the Internet of things to connect sensors and devices, process simulations for scenarios using digital twins, and robots or unmanned vehicles to perform manual tasks. Singapore anticipates using many smart features in its individual systems. For example, the drainage grid will have extensive hydrometeorological monitoring, the smart plants will feature automation, the smart water grid will include pressure flow and water quality, and the smart sewer grid will include illegal discharge tracing. When these features are fully operational, they will aid Singapore in its quest to be self-sufficient in water and to have greater water security.

Paju is a developing city in the northern part of South Korea, near the 38th parallel. Its population is about 425,000, and it has been the focus of developing a smart water system with the sponsorship of K-Water, South Korea's national water agency. Paju has

been explained as a case study is one of the selections in the study by the International Water Resources Association about smart water management.

Korea has devoted substantial attention to the development of improved integrated water management and the use of intelligent water resources operations technology to promote water security and improved operations [31,32]. This emphasis on using technology is carried out in conjunction with multiple objectives, such as water safety and security, and including a “tastier and healthier water supply”. This requires the use of smart water management to provide real-time information about tap water quality to gain public trust. K-water is pursuing objectives to manage source water, optimize water treatment, operate intelligent networks, customize industrial water supply, and optimize wastewater treatment. These goals are translated into water quality management, water quantity management, risk management, energy management, pipe network analysis, and demand forecasting.

So far, the major accomplishments of the Paju Smart Water City Pilot Project focus on improving the reliability of tap water, better customer service, and relieving distrust by citizens of tap water. Prior to the project, only about 1% of the population used water for drinking, but after the project pilot project, this percentage increased to 36.3%. Reports of satisfaction have also improved and the need for water purifiers will be significantly reduced.

Fort Collins, Colorado has an integrated utility where four services are managed together: water supply, wastewater, stormwater, and electric power. The city has recently completed a study of how to foster additional integration by linking raw irrigation water with its water supply system to utilize water sources and infrastructure better [33]. Fort Collins exhibits a small amount of water recycling, but its gravity water supply system would make it expensive to treat wastewater and pump it back uphill. Moreover, the water law system that operates in Colorado places certain barriers in place for water recycling.

The smart water features in the Fort Collins system are typical of those in US cities that are implementing new technologies. For example, the city has district metering areas with valves and remote pressure gauges, access to radar-based weather forecasting, and nondestructive sensors for main wastewater sewers. Fort Collins is customer friendly with its utility services and engages actively with water users by reporting about periodic water uses to encourage conservation. Fort Collins can access other technologies such as advanced metering infrastructure and real-time modeling for water distribution, and it implements them according to need.

The Juarez City case study addresses issues of a major metropolitan area in an arid zone. Juarez and El Paso are twin metropolitan areas coalescing as one urban region. Juarez draws its water from a binational aquifer in which management can be contentious [34]. The city has undertaken an aggressive smart water program based on measurement and control to interact with customers in proactive ways for water conservation. The features of the system are smart meters with high accuracy, pressure control valves, advanced metering infrastructure, and a web platform for customer outreach.

The project is to be self-funded and progress through 2021 has been promising. Implementation started with major users and will be extended to additional smart meter applications and system controls. The eventual goal is to eliminate most water losses, measure and manage water use carefully, and improve the capacity of the utility to continue to serve the growing city, despite water supply limitations.

More case studies are available, and a synthesis can be found in [2]. Many case studies of integrated approaches are also available [35]. The lessons learned converge on a few principal challenges. These will be summarized next, and future directions will be summarized afterward with the identification of trends that are evident from the cases.

## 8. Challenges to Integration

An understanding of significant barriers to implementing integrated and smart water systems has emerged from the pilot studies. Some of the challenges were summarized in the smart water management study by (IWRA, 2021), which had that as a goal. Other

barriers have been identified through studies such as [36], which assessed studies about the implementation of integrated strategies. The understanding of challenges converges to a few main problems.

Most barriers to integration deal with organizational stovepipes and the difficulty in merging or even gaining cooperation among public organizations [37]. Another challenge is the complexity of integrated urban water systems, with their different levels of infrastructure and operations management and their separate regulatory structures. To move the needle will require transformations in institutional cultures to overcome resistance to change. Concessions may be needed to overcome resistance to integration. For example, participants in one case study overcame stovepipes partially by allowing the merged organizations to retain their separate SCADA systems.

In terms of implementing smart attributes, financial barriers were identified most often, with a focus on higher-than-expected costs and lower revenues than needed. Lack of financial support for demonstration and training was also mentioned. A related barrier was the large amount of time and institutional commitment required.

The institutional commitment required competes with other capacity issues, which also pose limiting factors for the implementation of smart systems. Capacity is needed among staff to plan and manage programs, as well as from support organizations to provide services and equipment. For example, in support organizations, the large-scale demand for the production of smart meters may be a constraint. On the utility side, the task of reducing staff positions that perform traditional but now outdated functions can be difficult. Additionally, other stakeholders such as allied agencies must have enough capacity to participate productively, to understand, and support the transition to smart systems.

The local nature of water systems and the diversity it creates constitutes a barrier because, even if an approach works in one place, it may not be possible to replicate it in another with different conditions. This means that pilot studies may have limited applicability, except for very specific components or practices in smart systems.

It is also difficult to assess the benefits of smart systems if incremental performance improvements and providing enhanced information to customers do not yield politically attractive results in the near term. This problem, when combined with the limited funding for smart systems, may defer programs indefinitely.

Given the problems in large cities, the greatest opportunities for innovation may be in small and medium-size cities where different approaches in governance are more feasible. A reality in the vision of integrated urban water systems is the case of struggling cities where public services fall way below minimum standards [38].

Smart water cities hold the potential to improve quality of life and urban environments anywhere in any place where effective governance is in place. When it is, it seems inevitable that urban water systems will change and their performance will respond to the felt needs of people in the cities and that smart systems can help to effect behavioral changes such as greater confidence in tap water for drinking, water conservation, greater use of recycling, and improved urban water environments.

The behavioral changes will occur as people learn more about their water systems, which can occur through the provision of more useful and effective information about the systems. People can learn about health effects, positive environmental management, and preparation for emergencies, among other water-related subjects.

The model shown in Figure 2 provides a way to forecast how these changes can occur. The primary driver will be user information for daily needs and emergency preparation. People have ongoing needs for quality drinking water service, responsible wastewater management, drainage of properties, and common areas. While they may take the services for granted in some cases, with creative approaches to water education, better cooperative arrangements between water managers and water users can take place.

Organizational and governance changes required to facilitate future improvements are likely, although in some situations progress may be slow. Resistance to change is as deep roots both on an individual and organizational basis. Possibility for improvements

brought about by new technologies may drive change more rapidly than top-down political decisions intended to force changes prematurely. As new generations of water managers take the reins, they will be more familiar with technological possibilities and search for ways to change the way business is conducted.

With ongoing changes in technologies, it seems certain that unexpected possibilities will develop. The recent availability of social media, smart devices, wireless communications, machine learning, and others have ushered in management possibilities that were heretofore unknown. These have already changed many institutions and although urban water organizations may be slower and less agile than private businesses, they will change as well. The results should be positive to make systems more robust and reliable and for consumers is well, both in quality of service and in effectiveness.

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## Article

# Designing Geographic Information System Based Property Tax Assessment in India

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**Abstract:** Property tax is the primary source of revenue for municipal bodies. In India, municipal corporations are facing issues in property tax collection, and the primary reason for it is a lack of count of assessed properties under its jurisdiction. Also, the storage of information on the properties is mainly based on manual efforts, which leads to data redundancy and failure to appropriate tax collection. Geographical Information Systems (GIS) consists of technology, personnel, and resources to create, maintain, visualize, search, and share geospatial data and services. The study has been carried out in the Hauz Khas Ward, South Delhi Municipal Corporation, Delhi. This paper aims to develop a spatial database for property tax management. It includes capturing the building footprint, road, land use such as parks, paved area, drains, and demarcation of boundaries such as locality slums, based on a regular grid net with a cell size of 250 m by 250 m. The generated geospatial database has been finally used to evaluate parameters for property tax calculation. Moreover, this spatial database can be organized as different models for any web-based application for municipal services. This study provides a working example of a GIS-based property tax collection solution for whole of India and other South-Asian countries.

**Keywords:** property tax; GIS; geodatabase; spatial data; decision support system



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## 1. Introduction

Worldwide more than 130 countries collect taxes on the properties, and almost all countries consider it the prime source of revenue for the local governments to administrate effectively [1,2]. Moreover, developing countries rely on it more than developed ones and acknowledge the importance of so-called local tax [3,4]. Even in most of the developing countries, the local governments rely on property-related revenues to service out other essential services such as education and health [5]. Now that the global community has acknowledged the significance of taxation as a 'state-building' process, the practical consequences of implementing a strategy to tax reform require clarification and efficient procedure to implement.

Property tax is a levy on property that the owner is required to pay to the governing authority of the area where the property exists. For any development, property tax is one of the major sources of income state or country to cover the expenditure of development [6]. The local or municipal authorities are bound for the development of their administration, and without capital, it can become a challenge for them. Besides, taxation can be used as an urban management tool that can track land use, urban expansion, land market, and

transactions related to properties [7]. As a matter of fact, for property taxation, location is foremost as it matters to unit value for tax calculation. The location as a spatial attribute of property is crucial for the analysis or estimation of many aspects related to property or urban management.

India also has the same scenarios of revenue collections related to property. At present, there are about 3842 urban local bodies (ULBs) in India, wherein 2108 are Nagar Panchayats, 1595 are Municipalities, and 139 are Municipal Corporations. Mainly there are three sources from where ULBs generate their revenue, i.e., revenue shared taxes, exclusive taxes, and nontax revenues. The exclusive taxes include property, entertainment vacant land, advertisement, and professional taxes. While the property tax is the most important tax levied among all the taxes at the local scale. For any local or municipal body, property tax reflects the relation between the types of services financed at the local level vs. the benefit to property values. Hence, it is considered a good tax. In India, the state government is responsible for designing the property tax system, and the ULBs control the tax rate and collection planning.

In India, many studies have been carried out to lay down the taxation system of the properties. A study carried out by the National Institute of Urban Affairs (NIUA) in 10 Indian cities shows that the trend has shifted from the annual rental value-based system to an area-based system in many cities [8]. The area-based taxation is based on factors such as location, usage, type of construction, and age of the building. Many corporations have introduced the self-assessment scheme, and a few, like in Bangalore, have introduced online tax payment. As mentioned earlier, the success of reforms has been uneven. While the revenue productivity in Bangalore has shown a sharp increase, the revenues have continued to be stagnant in many other metros, including Delhi [9].

Noncompliance with property taxes is common in south Asian countries, and it can worsen their liquidity problems [7]. Revenue elasticities and metrics of taxpayer hardship are used to characterize optimal enforcement and taxing regimes [5]. These characteristics are calculated utilizing a variety of sources of variance as well as administrative data. Rate hikes and increased enforcement generate revenue, but liquidity restrictions also influence taxpayer behavior [4]. Despite liquidity restrictions, increasing tax rates improve wellbeing. On the other hand, enforcement has larger private expenses than welfare benefits. Mostly on margin, welfare-maximizing authorities would instead raise tax rates than strengthen enforcement [3]. Therefore an efficient system is required for assisting the collection and management of the property taxes.

Property tax can be a significant source of revenue, but practically it fails to collect expected revenue efficiently. In Delhi, the method of tax calculation is unit based for which many factors are required, such as property address, colony name, colony category, no. of floors, covered area, vacant land area, type of property (residential/commercial), type of occupancy (owner/tenant), type of structure (kaccha, pacca, semi pucca), year of construction and owner type (single/joint). A door-to-door ground survey is essential to complete this database. Proper assessment of properties and efficient tax collection are vital for the ULBs. The current infrastructure has insufficient information to ease the process of tax status verification. For tax inspectors, it is imperative to identify the defaulters who are not paying appropriate tax in terms of its factors or not paying at all. The good thing about property taxation is that the primary object, i.e., property, is immovable. But again, if you don't know its location, you can't manage it. Therefore, many municipal bodies are planning to adopt GIS-based property tax systems to boost their revenues. GIS is a modern system of tools for effective and efficient storage, retrieval, and manipulation of spatial and non-spatial data for attaining efficient management and policy-making information [10]. GIS can provide a system for inputting spatial data and intelligence for planning and monitoring project implementation [11].

GIS is used to locate assets, track information, and save an organization time and resources. Multiple analyses can be done on a database that can be readily displayed on any GIS-based platform with various color-coded parameters that the corporation's officials

can easily interpret. One can quickly identify the number of households who want to know the defaulters in their assigned area. It provides a visual result in a hard copy or digital map about where those properties are located. Moreover, it was challenging to identify the impact of location on land value as determining accurate location was very challenging [12]. Nowadays, using GIS, to analyze spatial attributes of any number of entities is relatively easy [13–16]. Also, GIS mapping is of great significance in scientific research, planning, and management [17]. GIS technologies can handle large volumes of data from multiple sources, integrating them to produce information in a spatial context through maps and models [18]. Applying GIS-based municipal information tools can lead to the solution of these data management problems. Thus, GIS can be a handy tool for municipal planning and decision-making that evaluates and assesses assets. Not just worldwide but also in India, many local and municipal governments use GIS as a decision-making tool to design and support development programs [19].

This study is a pilot study to be carried out for the whole of India initially with the four major metropolitans, Delhi, Mumbai, Kolkatta, and Chennai. The present study is the representative study of one of the wards of South Delhi, i.e., Hauz Khas. The agency responsible for levying the tax on properties in South Delhi is South Delhi Municipal Corporation (SDMC). The present work aimed to create a geospatial database of all the properties present in Hauz Khas to take them under the tax net of SDMC. In Delhi, the property tax calculation is based on the unit area method. Since 2004, the collection of property tax has been moved to the self-assessment method. Since then, the number of assessed properties has decreased [20]. Also, because it is a self-assessment basis, SDMC has information for those properties that have filed the property tax. The properties which have never paid the tax have not come under the notice of SDMC. Therefore there is an ever-increasing need for digital spatial data to be more feasible and reliable for this decision-making system [21–25].

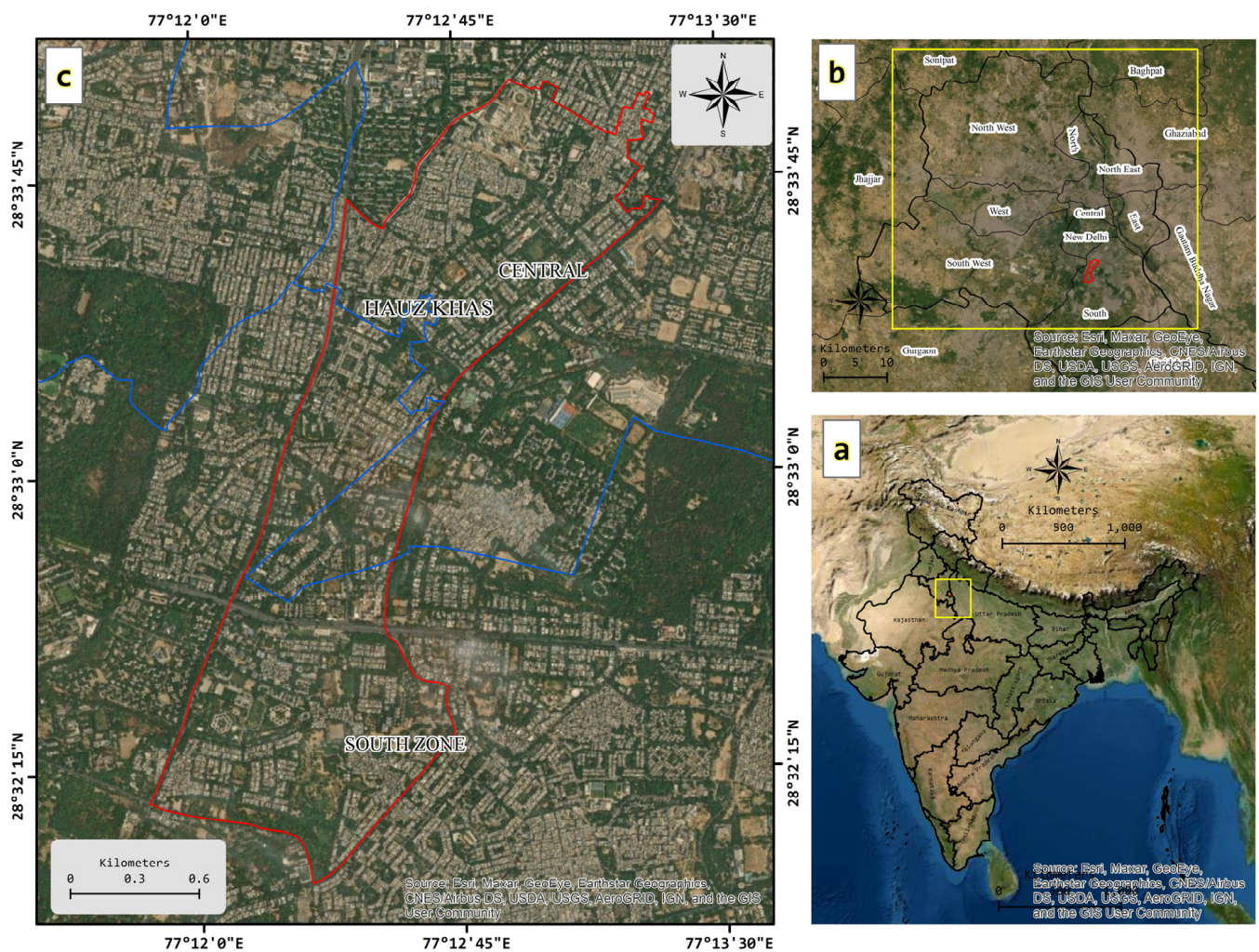
The paper demonstrates the need as well as how a successful spatial database consisting of multiple layers in GIS environment is created to provide a solution through ground reflective analyses and could be easily accessed through an intranet or internet application [26–28]. This work is also designed as an enterprise GIS for municipalities all over India that can customize attributes and geospatial data with spatial and non-spatial models and operations to create a service-oriented architecture from Geo web services [29–32]. The study also demonstrates how planned spatial data (attribute and non-attribute) such as building footprint, roads, drains, parks, location boundaries are digitized for the jurisdiction of Hauzkhas Ward, South Delhi Municipal Corporation, in the GIS environment.

## 2. Materials and Methods

### 2.1. Study Area

Delhi is located at a latitude of 28°34' N and a longitude of 77°07' E, having an average elevation of 233 m (ranging from 213 to 305 m) above the mean sea level. The NCT has three local municipal corporations: Municipal Corporation of Delhi (providing civic amenities to an estimated 13.78 million people), New Delhi Municipal Council (New Delhi), and Delhi Cantonment Board. The total geographic area of Delhi is 1483 km<sup>2</sup> (Rural-689 km<sup>2</sup>, urban-624 km<sup>2</sup> and forest-170 km<sup>2</sup>). Recently Delhi Municipal Corporation of Delhi has been trifurcated into three smaller Municipal corporations—North Delhi Municipal Corporation, South Delhi Municipal Corporation, East Delhi Municipal Corporation. Among all the corporations, South Delhi Municipal corporation is the largest one, having 667.38 km<sup>2</sup>. The South Delhi municipal corporation is further divided into four-zone and 104 wards. Hauz Khas ward (Ward No.62S) falls under the South Zone of South Delhi Municipal corporation (Figure 1). It consists of planned, unplanned as well as commercial properties.





**Figure 1.** Location of the study area. (a) India, (b) Delhi Municipal Corporation, (c) Hauz Khas ward.

## 2.2. Methods

For this study, the primary concern is building, as it is fundamental for property tax calculation. For the level of visual interpretation required in this study, WorldView-2 imagery has been used. The resolution of the world view is 0.5 m which was suitable for the interpretation of building edges and partitions. A visible feature like building, land-cover, drains can be captured using this image, but the boundary of localities is not possible with it. For interpretation of localities, blocks, colonies, other sources such as Google or Eicher maps are useful. For this paper, a reference to Eicher map-2007 and Google map has been used. ArcGIS (version 10.1), an ESRI suite platform, was opted for geodatabase creation. Figure 2 shows an overview of the overall methodology.

The primary data, i.e., categorized property data, was collected through field surveys using the property tax form (Annexure 1, 2). The secondary, i.e., wards boundary gazette notification, slum boundary list, enumeration block extent list, SDMC property tax form, and colony categorization lists have been collected from the concerned departments. The unique key between the property survey form and spatial data of the building was proposed to be an identifier referred to as BUID. On the platform of ArcGIS, the survey data have been mapped using the *geocode tool*. The survey data led to creating three related layers, i.e., building, properties, and unit.

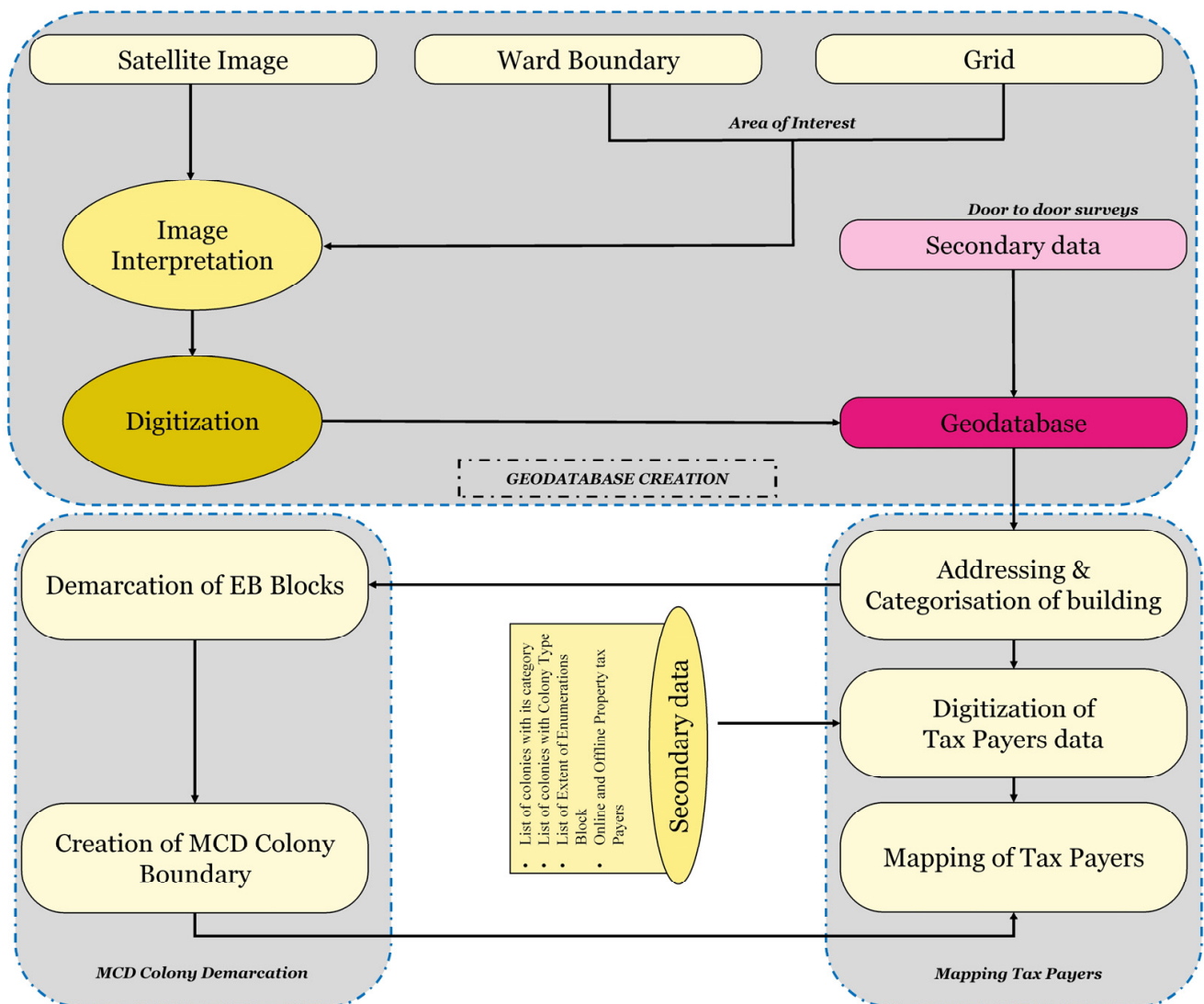


Figure 2. Overall methodology opted for in the present study.

Since for property taxation, “Property” is the foremost requirement, and it can be one building or part of a building or cluster of buildings. During digitalization, all buildings have been assigned a BUID with a unique number for each building so the polygons can be used to map real-world properties. All buildings were assigned with a reference number ranging from 1 to N within the Grid, where N is the maximum count of buildings in any grid having limits of 99999. This reference number was formulated as a five digit alphanumeric text. To make it 5 digits, an additional pre “0” has been added to the attribute’s reference number (RN). For example, if the given Grid no. 30274, the building has been given reference no. from 1 to 114. The building Id will be “00001”, 00010, 00100, etc.

The unique reference number (URN) is a 10-digit number combined with Grid number and Building ID. This was a means of creating a unique reference number for each building throughout the data. In Table 1, the design and creation of BUID have been shown.

**Table 1.** Creation of Building Unique ID.

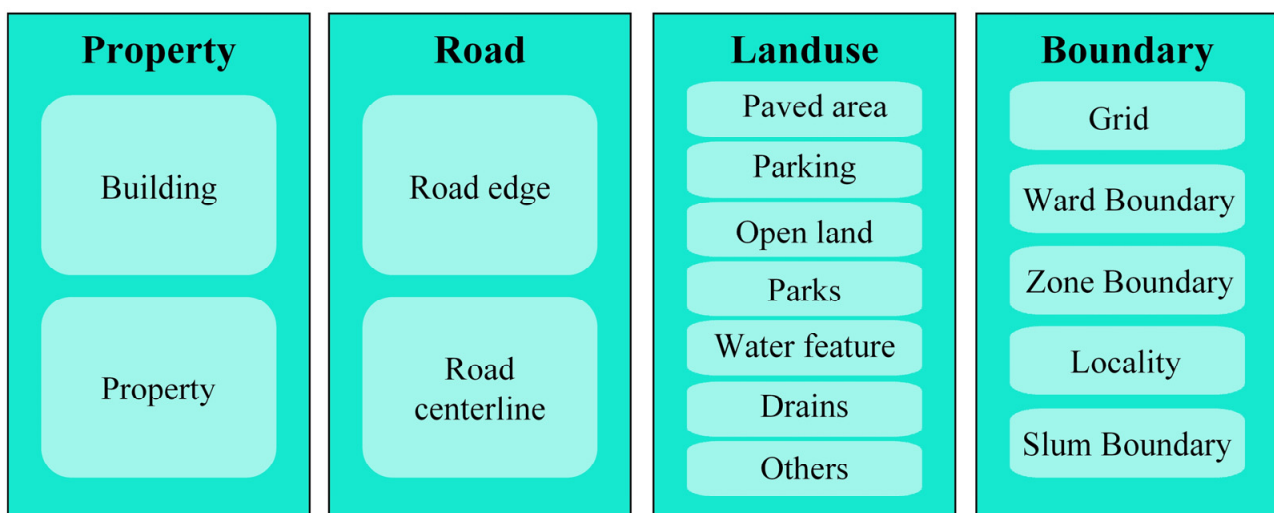
Map Number	Building Reference Number	Building ID	BUID
30274	1	00001	3027400001
30274	2	00002	3027400002
30274	81	00081	3027400081
30274	82	00082	3027400082
30274	112	00112	3027400112
30274	113	00113	3027400113

For digitization of location boundary, Eicher image has been used. Eicher is an image having visualized major base layer information. The colonies and locations are generally separated by any natural or manmade boundary such as road, drain, building, or landcover pattern. A Reference Google image has also been taken for this task. Information like the name of a major road, major drains, localities, and major landmarks has been added in the data using Eicher and Google.

### 3. Results and Discussion

#### 3.1. Geodatabase of the Implementing the Property Tax

Understanding the ground reality in terms of available features, structures, and economic activities is essential to creating any management and planning activities for any area. This requires digitization of all the available features on the ground, such as buildings, lands, forests, water bodies, and roads within the municipal boundaries [33–37]. This is wherein GIS-based geodatabase plays come into play. The data captured as a .shp file and stored in a .gdb format at the ESRI Platform forms the data input process. The geodatabase is a structured way to store multiple shapefiles of different feature types, whether point or line or polygon [38]. The structure of the geodatabase used in this study is presented in Figure 3. The set of shapefiles has been categorized in geodatabase based on its entity type. Before capturing the data in the shapefile, required fields with the name have been created as per the data type and field length.

**Figure 3.** Geodatabase structure of the Hauz Khas ward (I).

There are four major geodatabases (.gdb) categorized in the present work, i.e., building, road, land use, and boundary, under which various other essential information layers are stored either by digitization or creation. One of the important layers in this project is a grid of 250 × 250 m which is the base for creating a unique ID for building and property survey maps. Each Grid is assigned a unique number, and each building with the Grid has



also been assigned a unique number. A combination of both the numbers at the Grid and building will create a unique ID for the building, i.e., BUID (Figures 4 and 5).

On the ground, there are multiple properties. By assigning a unique no. to each property within the building, it will create a Unique ID to each property. In another way, the concatenation of Grid no., building no, and property no. will create a Unique ID for property (PID: Property ID).

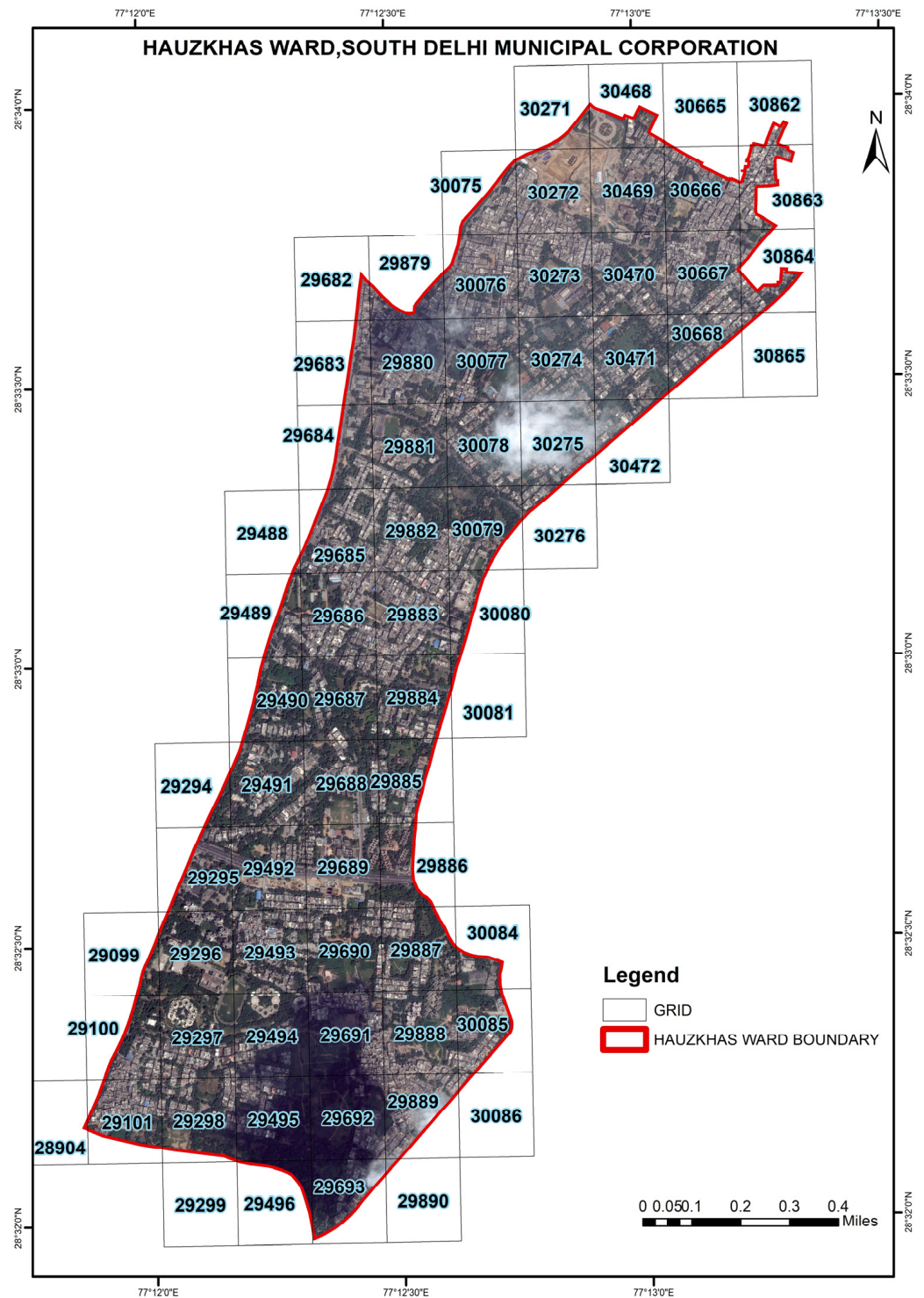
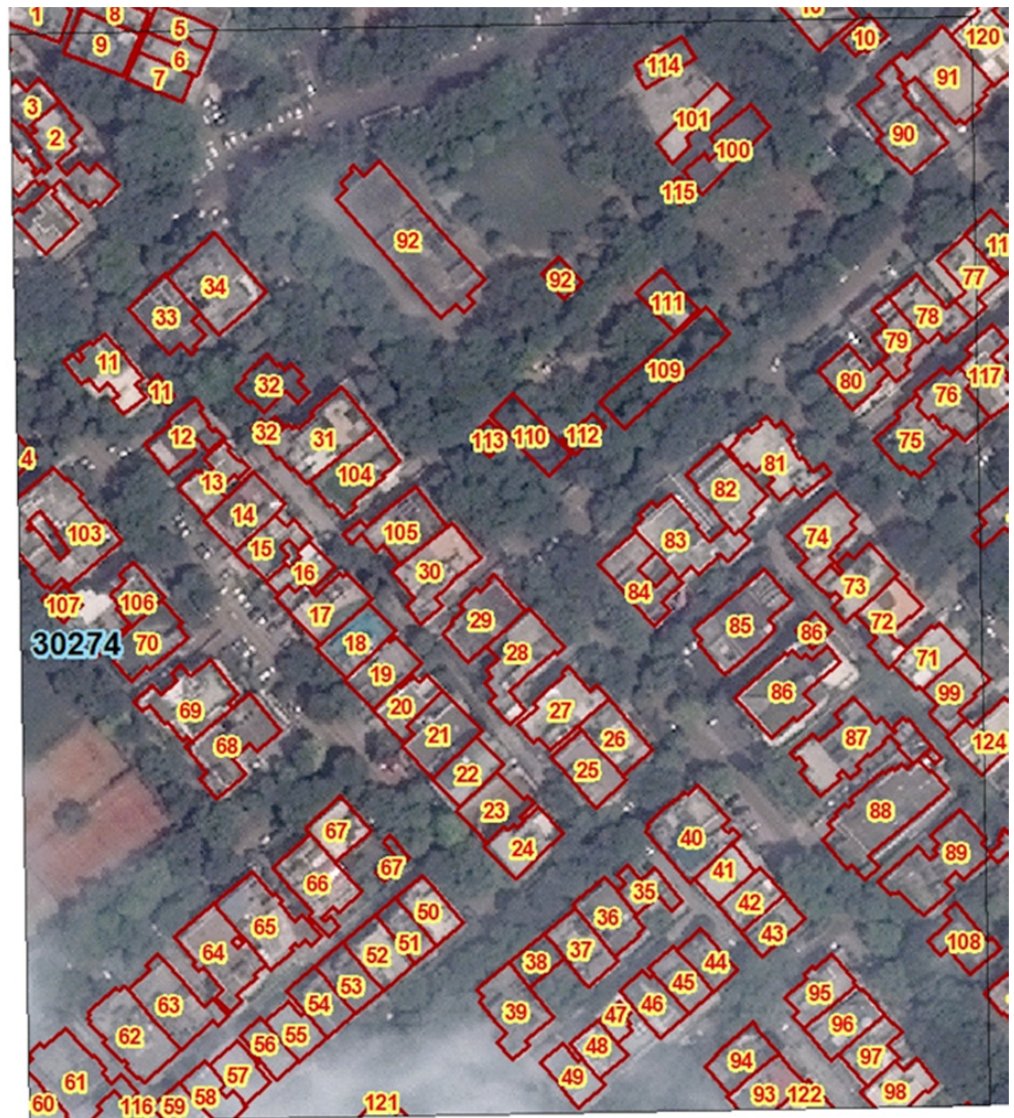


Figure 4. Geodatabase structure of the Hauz Khas ward (II).

The creation of spatial data is majorly an image interpretation job. Before capturing any building, a  $250 \times 250$  m grid has been created. This Grid has been created using the fishnet tool in Arc GIS [39]. Each Grid has been assigned a unique number. The same grid number will be updated in the building under the respective Grid. It will not just help in tracking of digitization of data but also will help create a unique ID for Building.



**Figure 5.** Reference number (RN) for each building in the Hauz Khas ward.

SDMC colony boundaries were mapped starting with the enumeration block. Enumeration Block (EB) means a specific area allotted to one particular enumerator to carry out census operations relating to population enumeration. The State Election Commission defines these EB Boundaries. SDMC uses these EB Boundaries to form SDMC colony boundaries. The municipal valuation committee decides the category of colonies. The boundary of wards and colonies is most likely to change within its Assembly constituency boundary every five years. Demarcation of EBs on the digital platform is a one-time exercise that will be a base for future modification of ward or colony boundaries.

The digital profile of the Hauz Khas ward has been created, which has visual information of building, road, use of lands, and locality. Land use and land cover information are important for several planning and management activities concerned with the surface of the earth [40,41]. The land-use types are estimates of the study area is given in Table 2. The

land use distribution can define and predict human activity using agriculture, housing, or institutional. Ward area of Hauzkhas is 3.14 km<sup>2</sup> having 5620 buildings under its jurisdiction. The covered area of the building is 0.93 km<sup>2</sup> in Hauzkhas, i.e., 29% of the area, which is the tax-net for the SDMC (Figure 6). Through this approach, only horizontal expansion of built-up can be determined. Still, again for the actual covered area, it is imperative to calculate the vertical built-up, which can be best possible through the door-to-door survey of these buildings. Apart from this, approximately 20% of the area is covered by roads and paved areas. Since the Hauzkhas ward is planned, 23% of the area has been dedicated to the gardens and park. Since many of these portions are owned privately, this can be maintained the same in consecutive years. One more thing is very focal in this study for the municipal that approx. 23% of the area is open land, which is prone to have unauthorized construction leading to unauthorized colonies.

**Table 2.** Land use/Land cover of Hauz Khas Ward estimates.

Land Use	Area (m <sup>2</sup> )	Percentage
Water Body	0.02	0.005
Building	92.57	29.50
Open land	72.36	23.06
Others	12.11	3.86
Park	72.48	23.09
Paved Area	26.87	8.56
Road Edge	37.45	11.93

Apart from the land-use profile, this database has also resulted in a building polygon with a unique ID. The decided range for building reference is 99999 for each Grid, which is quite enough as each Grid area is 250 × 250 m<sup>2</sup>. The 250 × 250 m grid size is a requirement under the Government of India guidelines to map buildings within such grids under this framework. Very high-scale grids would complicate the GIS-based processing and shall require more computing power (storage and processing). Therefore the 250 × 250 m grids were selected after various hit and trial experiments to avoid computational and data storage issues and, at the same time, was fair enough to provide a rigorous comparison.

Since the data type of Building ID is alphanumeric, an alphabet can be added to the ID for any adverse condition such as partition or new building construction in the same building.

This BUID is key to smooth access of these polygons to use it to collect property information through field surveyor to link it with other digital databases or to map any other attributes. For the development and maintaining the ward, this exercise can provide a foundation where multiple analyses and predictions can be made.



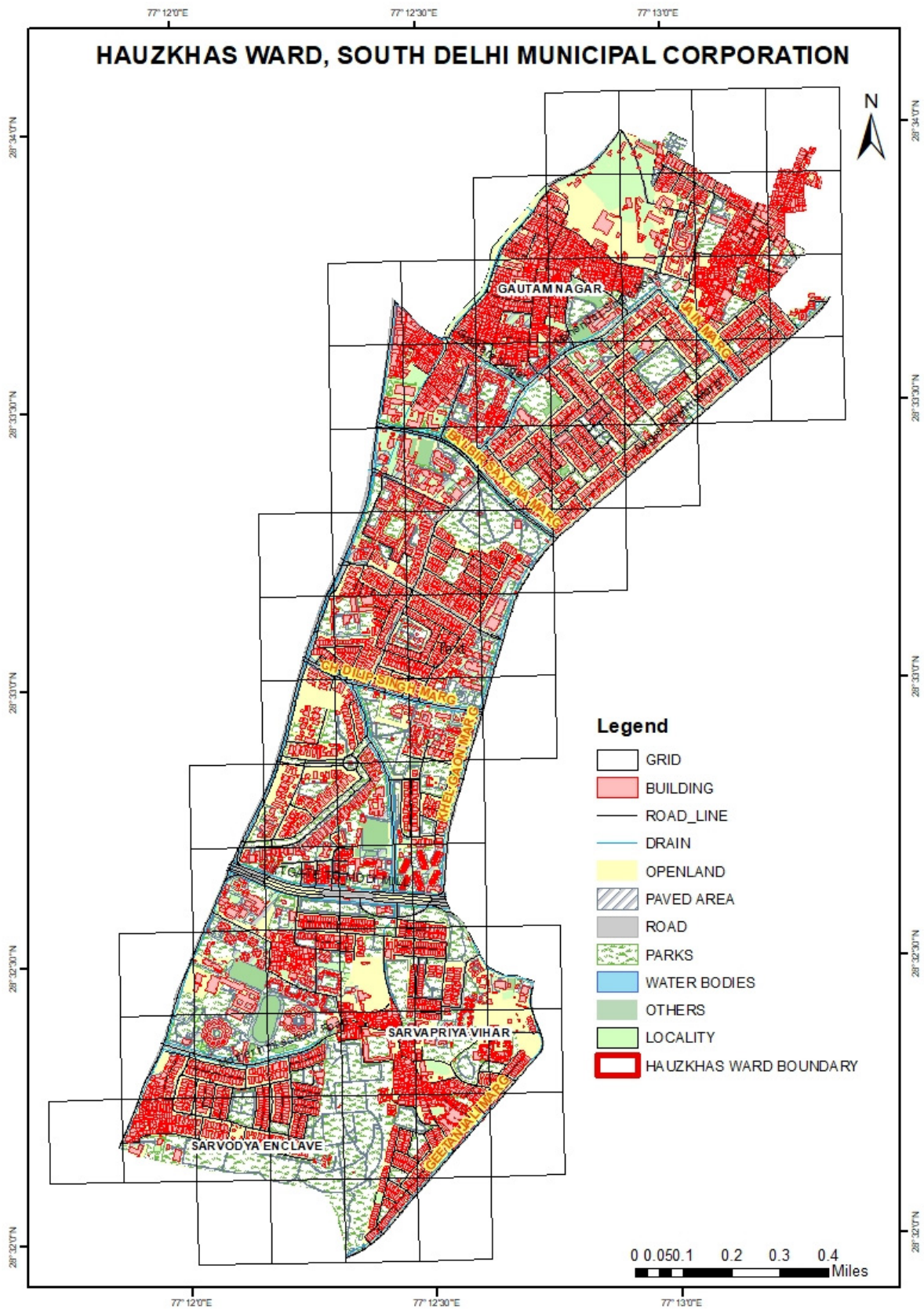


Figure 6. Land use map of Hauz Khas Ward.

### 3.2. Property Tax Implementation

Property tax isn't used to its full potential due to low property valuation rates and ineffective revenue collection. Municipalities and local civic bodies' largest difficulty today is defining improved property valuation procedures, keeping a regular track of income receipts, and calculating losses on exemptions [42]. GIS aids in the monitoring of property tax revenue by establishing a platform that spatially interconnects all property-related data, such as the number of storeys in each building, the total structured area of each building, individual plot areas, locality details, and municipal colony boundaries, to the tax calculation principles.

The formula of property tax is

$$\text{Annual value} \times \text{Tax Rate}$$

In Delhi, the rate of tax is divided into eight categories from A to H (Table 3).

**Table 3.** Rate of Colony Categories for Property Tax Calculation.

Category	Residential Property	Commercial Property	Industrial Property
A	12%	20%	15%
B	12%	20%	15%
C	11%	20%	12%
D	11%	20%	12%
E	11%	20%	12%
F	7%	20%	10%
G	7%	20%	10%
H	7%	20%	10%

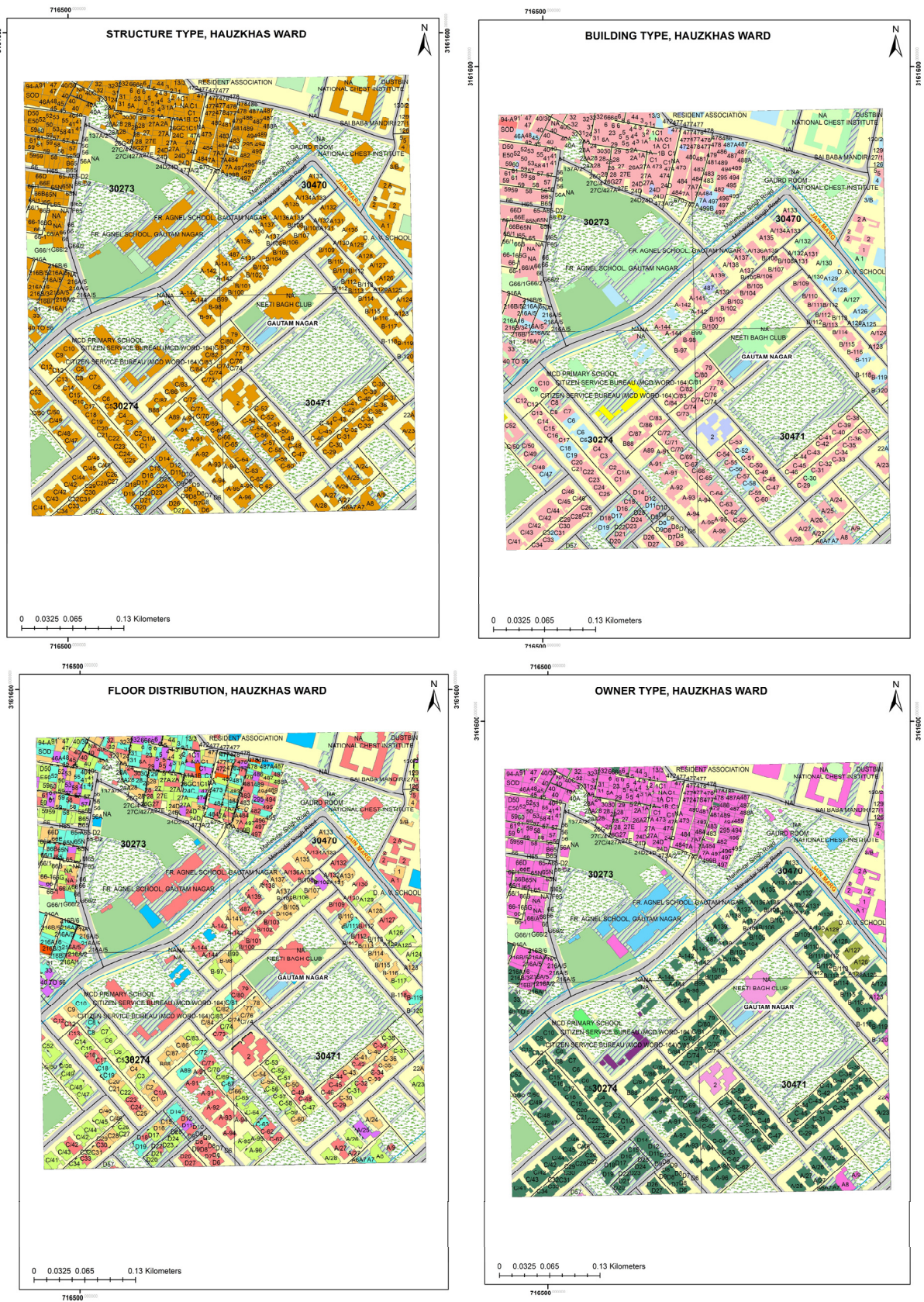
To devolve a robust database, the creation of thematic maps of the property tax formula parameters will be a major advantage. For example, the database will have visible information like use factor such as commercial, residential; Age factor means a year of construction of the building; Structure factor such as kachha, pucca; Occupancy factor such as self-occupied, tenants.

$$\text{Annual value} = \text{Unit area value per m}^2 \times \text{Unit area of property} \times \text{Age factor} \times \text{Use factor} \times \text{Structure factor} \times \text{Occupancy factor}$$

Apart from this, many other rebate factors are applicable for tax calculation. More the variable stored in the database directly proportionates to the improvement of the database. Access to these kinds of the color-coded map through the administration system of property tax will be boon for the tax inspector. It will be easy to identify and verify the values given by taxpayers. The GIS information layers are shown below as maps (Figure 7a,b).

Also, for calculating annual value, one of the factors is Unit area value per m<sup>2</sup> which is the assigned value per square of meter built-up area of the property. It also varies on colony categories.





(a)

Figure 7. Cont.



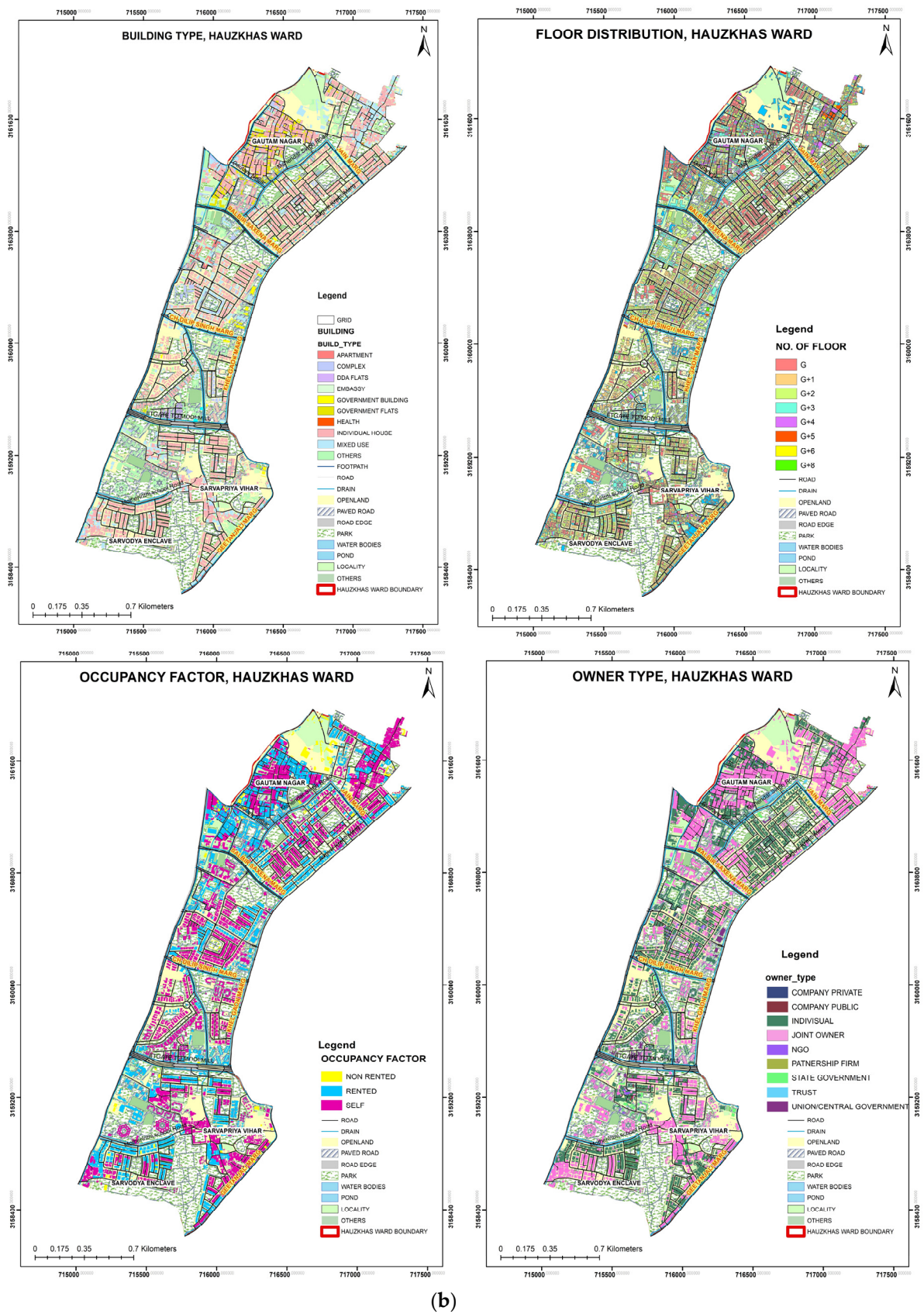


Figure 7. Information required for calculating the annual tax i.e., structure type, building type, floor distribution, and owner type. (a) Zoomed-in view (b) Overall Hauz Khas.

### 3.3. Mapping of Taxpayers Data

There is no regular monitoring of whether property tax has been paid or not. As with the case of property tax, there is no assessment of whether owners make proper property taxes in terms of its factors. In the current system, there are various blockers to identify such defaulters. If any tax has never been paid for any property, then the record of the property does not exist in the database. Even the tax for the property has been paid since property tax payment is a self-assessment method, so to verify the details of property provided by the owner, the only option for a tax inspector is ground verification (Figure 8).

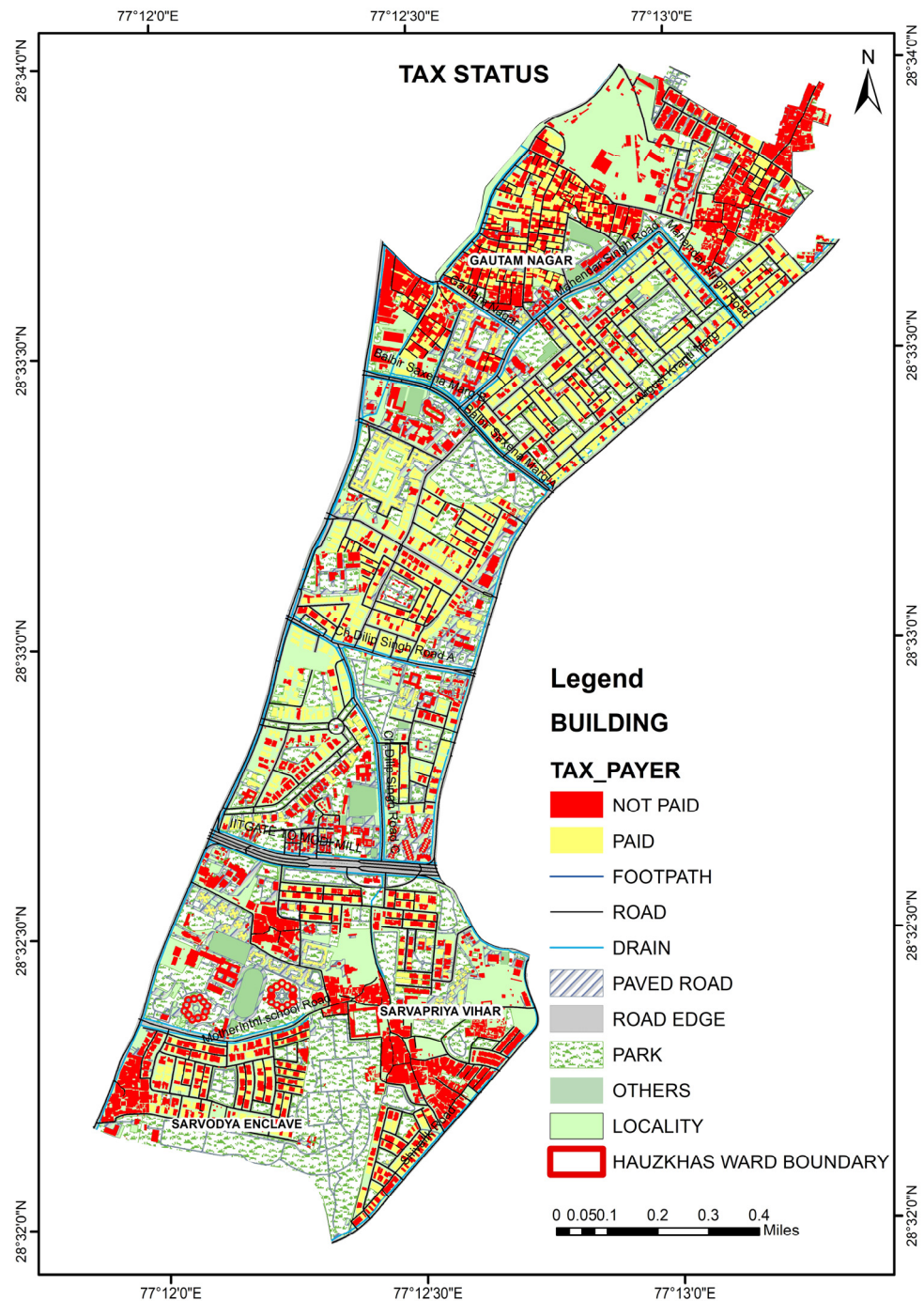


Figure 8. Annual tax payers status in the geodatabase.

Using the spatial digital property database would be a systematic and easy process to identify these issues [43]. SDMC has two types of taxpayer data: Online tax data paid by the taxpayer using an online portal and a ledger that has information on those taxpayer data that pay tax offline. Both the data contain information about taxpayers, including addresses and arrears. Joining SDMC taxpayer data with the property database helps bring out the required quality for developing an application that includes correlation and computerization of owner details and tax-paid history on the spatial platform to visualize the property from all aspects. After spatial joining and data sorting, analysis is done on each record to identify the status based on criteria, i.e., tax Paid and Not Paid (Figure 8). The final analysis result will be colony-wise sorted spatial data with information of property details on the ground and given by the owner concerning its tax history.

The amount of money collected from property tax in India is currently low. Its revenues currently account for just 0.2 percent of India's GDP, but it accounts for 3 to 4% of GDP in wealthy countries such as Canada and the United States [44]. Even a small increase in revenue from these might help local municipalities significantly grow their infrastructure, perhaps enhancing their development operations. Therefore an efficient property tax system is essential for development at grass-roots levels in India.

In fact, every country works in the field of its economic development and pushes itself to rise with other global powers. This is a joint exercise between the government and the people [45,46]. Taxation is one such system that acts as a feedback loop [47]. The government necessarily has to establish a system that would help the people have enough money to keep up with the rising output scales of any form of taxation. With automation gaining a central stage in India, various options are available for people to participate in the economic cycle. While industrialized countries already have significant shifts in revenues from the taxations, developing countries like India are trying to cope with their pace with the systems like the one discussed in the present study. Various studies suggest that developing countries should deliberately implement automation to maximize the financial outputs [48,49]. This study attempts to address India's progress in tax automation in the form of spatial information systems, GIS. Existing property tax collection systems do not try to close the gap in the efficient assessment of the taxes [50]. Most crucially, planned GIS-based automation must be implemented through solid regulations that recognize property-specific flexibility and allow reinstatement methods to achieve effective economic returns that ultimately help in restoring ecosystem services [51,52].

#### 4. Conclusions

The study demonstrates the working process of a geospatial database of various information parameters to calculate the property tax in the Hauz Khas ward of South Delhi. A well-organized geodatabase is created with four main types of information databases, building, road, land use, and boundary. Within these, a lot of other parameters, e.g., property address, colony name, category of the colony, no. of the floor, covered area, vacant land area, type of property (residential/commercial), type of occupancy (owner/tenant), type of structure (kaccha, pacca, semi pucca), year of construction and owner type (single/joint) were incorporated aimed at the calculation of property of the study area. For property taxation, there are mainly three steps, i.e., identification of properties to be taxed, accounting and creation of tax based on property parameter, and collection of tax, including arrears. All this information was collected through the image and a door-to-door ground survey to complete this database. The created database will make this process effortless and in time. It also provides control to secure the database and can be backed up to prevent data losses. Again, maintenance and updating of the database are much faster than the current hardcopy data format. It can overlay with any other layer, such as planning the layout of the development area and roads. This database can be used by other administrative divisions and will be easily upgraded by exchanging information of property tax department with other departments. So, the cost can be shared by multiple divisions of government. On the other hand, it will provide a channel for the



interaction of citizens and municipalities. Both parties can access the data with different rights of control. Having all information on the property will bring transparency in local taxation. Municipal applications need databases at a large scale for micro-level planning. Digital database creation is the primary and most crucial step towards development. Since the data has been captured on the GIS platform for fieldwork activity and the transfer of multiple attributes of field data, it will act as a powerful tool. Again, for the evaluation and development of colonies, other information on infrastructures such as type of road and drain and governing bodies is vital. This one-time task will be the key to multiple solutions to municipal challenges. This database can systematically store historical, current, and future databases and be utilized for analysis or development. Since there are many GIS platforms, this can be used and accessed through any IT-enabled GIS application.

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## Article

# Outline and Impact of Firms Related to the Third Industrial Revolution: Investigation through Big Data

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**Abstract:** This article is focusing on the dynamism of the Third Industrial Revolution (TIR) in the region Hauts-de-France between 2013 and 2018. Region Hauts-de-France has been a forerunner in setting up a proactive policy in favour of the TIR. It provides a relevant and suitable context for the identification of TIR activities. We assess the job dynamism of the TIR through the implementation of big data methods for the identification of the firms involved in the TIR activities and the collection of firm microlevel data. We provide evidence of the strong dynamism of the TIR activities in a context of weak regional dynamics. We show that the growth in employment arises mainly from renewable energies, positive energy buildings, circular economy and energy efficiency. Future researches are encouraged to investigate the quality of employment and to question the distinctive characteristics of the firms involved in TIR.

**Keywords:** Third Industrial Revolution; sustainability; growth; jobs; circular economy; function-based product-services systems; renewable energies; positive energy buildings; energy efficiency; mobility



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## 1. Introduction

Employment growth, or more generally value creation, derived from activities related to the TIR is a sine qua non condition for its strong sustainability. Besides, sustained economic growth and the creation of decent jobs for all make one of the key Sustainable Development Goals (SDG) set out in the United Nations 2030 Agenda for Sustainable Development. In the short term, demonstrating that activities related to the TIR contribute to creating jobs will lead to societal acceptance of the destruction involved in substituting carbon-based technologies, and will foster the investment of innovative firms in these sectors [1]. It is considered by some authors as an effective strategy to revitalise the economy of developed countries and it materialises strong expectations from public policymakers [2–7]. Insofar as the shift toward TRI inevitably comes with job destructions as activities that emit carbon disappear, the question of whether the TIR can lead to net job creation is non-trivial [8]. Despite the importance of job creation related to the TIR, there is some debate about the assessment of its positive impact on net growth in employment. Ref. [8] (Table 1, p. 759) report that empirical studies are not unanimous. Although a majority of studies show positive effects [9–13], others show either a negative [14] or absence of [15] effect on growth in employment. However, recent empirical literature has highlighted more positive effects [2,8]. It should be noted that these studies concern the green economy, which scope goes beyond that of the TIR.

Surprisingly, France has very hardly been studied. Most fall under grey literature and originate from public organisations charged with the transition [16–19] (pp. 21–22 and pp. 81–82). Their results are oftentimes extremely optimistic and based on strong assumptions, such as that of full sectorial and geographical mobility of workers [4,20]. These assumptions, even though they hold little realism, are essential to overcome the difficulty of identifying green organisations and jobs, owing to the mismatch between existing sectoral benchmarks and sustainable activities definitions. The difficulty of identification results from the technophile definition of TIR activities, which does not easily adapt to existing

sectoral codifications [21]. Furthermore, these studies are very rarely specific to the TIR activities. Our methodological approach partially solves this issue in combining big data and legal expertise with a view to gradually identified the firms involved in the TIR activities. From the data collected with businesses, we estimate job creation in a similar fashion as INSEE (Institut National de la Statistique et des Etudes Economiques is the French national office of statistics.) and use the end-sizing method to simplify the comparison of our results with local and national censuses. As [3] advocate, we gradually refined the list of firms from a broad census to those with a core business related to the TIR. From the methodology employed in our research, a precise census of firms involved in the TIR has emerged. This facilitates the way their evolution is to be monitored, the way in which their transition is better supported, and the assessment of its economic performance. It is also still important to better estimate the number of green jobs on the territory to foster the implementation of efficient local strategies—for instance, to adapt regional policies and plans regarding skills [22] (p. 1056). The originality of our paper also lies in our focus on the dynamics of employment growth in firms based on their level of involvement in the TIR fields. To our knowledge, no previous research has led to the microeconomic evaluation of the positive impact of TIR activities on the evolution of job opportunities in France.

Our results confirm that firms focused on TIR saw their dynamics increase between 2013 and 2018 with an average employment growth rate of +17.38 percent in a context of weak regional dynamism (+1.34 percent). This trend is amplified for the firms strongly focused on transitioning with an increase of +21.09 percent. Our analyses are broken down by field of activity and show that the growth is mainly supported by the transition to renewable energies, the development of positive energy buildings and circular economy. Firms focused on the fields of production of energy storage systems, energy internet and function-based product-service systems are harder to identify either because they are at an embryonic stage, or because of the lack of information to qualify their business model (e.g., function-based product-service systems). Finally, the analysis of the situation in the five districts shows that the development of TIR in the Hauts-de-France is homogenous insomuch as no regional specificities can be noticed regarding the various fields. We present the literature review and the research context in Sections 2 and 3, respectively. In Section 4, we explain the methodological approach used to identify firms involved in the TIR activities. Section 5 shows and discusses the regional and national findings, as well as findings for each field. Section 6 discusses the contribution of our method but also its limitations and avenues for future research.

## 2. Literature Review

The fight against climate change and the transition to a sustainable economy require actions from regions and countries, and international cooperation [6,7,23]. In this perspective, the European Commission is implementing its Green Deal policy with the help of the public authorities and local private actors to come to carbon neutrality by 2050 and to the creation of sustainable economic growth and subsequent job creation. The interest of policy makers for the TIR is enhanced by the fact that the related jobs are expected to be higher skilled [24,25] and not easily relocated [26]. As the growth and composition of employment related to the TIR is intrinsically intertwined with the policy makers' investment, innovation and normalization strategies in green economy [2,8,27,28] probing how the TIR can be a driver of growth and job creation is thus crucial to provide the public policymaker with guidance for these actions.

Numerous studies have supported the idea of positive dynamics that the TIR—and green economy more largely—has on job opportunities in several political and technological contexts. Reference [12] show that the transition towards a zero-carbon energy production in China resulted in 472,000 net jobs gains. Reference [2] assert that the Scottish policy in favour of green economy led to an increase of more than 72,000 jobs between 2011 and 2014. Following [8,21] report that policies in favour of green economy boost innovation and employment in the EU, the US and Japan. In the same geographical area [29,30] the

development of wind power technology has fostered job creation. Conversely, older studies cautiously point to some neutral or negative effects [14,15,31,32].

Even though most of the recent contributions state that the TIR related activities are prone to growth in employment, it is of importance to note that differences in metrics, methods and contexts limit the generalization of the results. First, the estimation of the growth in employment related to the TIR depends on the scope: direct, indirect or induced employment. Direct employment refers to jobs observed in organization in targeted industries, indirect employment concerns subsequent jobs resulting from changing in the targeted industries/organisations and induced employment results from the jobs generated by the activity of both direct and indirect jobs [12]. Secondly, the range of TRI jobs may differ. As in green economy, some authors adopt a purist approach considering the jobs that restoring or preserving environment, while others refer to broader definitions including wider impacts [2,33]. Thirdly, the technological context of implementation of TIR activities and its interaction with regional/national policies is inherently linked with the growth of jobs [2,34,35]. Given the context, the proportion of employment related to conversion, to new or emerging fields or greening of existing skills may differ and may have different impacts on the indirect or induced jobs.

Regarding the specificity of the French technological context—characterized by small renewable but strong nuclear attachments resulting in low carbon emission in energy production [36,37] (France reaches the highest proportion of electricity production from nuclear sources in the world with 77.63%, while it is ranked 60th for the production from the renewable energies excluding hydroelectricity account for 6.2% (Source: WorldBank).)—France provides a relevant context for the analysis of the development of TIR activities. Whereas many contributions focus on the growth associated with the transition in the field of production of energy, the importance of nuclear power plants limit growth potential and implies to consider other aspects of the TIR. Furthermore, France invested of 3.5 € billions between 2013 and 2017 for the transition in the perspective of the creation of 470,000 jobs. Surprisingly, the French dynamic of the TIR has remained relatively unexplored. Most of the analysis of the dynamism of the French job market related to the TIR fall under grey literature and are released organisations in charge of the transition [16–19] (pp. 21–22 and pp. 81–82). Then, the results must be cautiously considered. As ([4], p. 24 in [2]) note *Uncritical acceptance of optimistic estimates of green job growth is especially ill-advised, given that these are typically produced by organizations and groups with a “vested interest in the outcomes”*. Besides, results of these studies are generally extremely optimistic and based on strong assumptions, such as that of full sectorial and geographical mobility of workers [4,20]. The PPEC (“Plan de programmation des emplois et des compétences”) report on the jobs and skills programming plan (PPEC, 2018 pp. 21–22 and pp.81–82) lists 22 studies published between 2010 and 2017. With the exception of the National Treasury (Direction Générale du Trésor) (2010), they all underline the jobs creations. This lack of research arises mainly from the difficulty of identifying firms involved in the TIR activities. Contrasting with Scotland or the US, France did not adopt O\*NET classification of green occupations and as the [20] confirms: *“it is proven impossible to identify jobs related to energy transition by mining directly from official classifications based on PCS (jobs and socio-professional categories) or ROME (Operational Directory of Occupations and Jobs), respectively used by INSEE and Pôle Emploi, the French employment agency. The classification of “Familles Professionnelles” (FAP) (professional “families” or groups), built by DARES to bridge the gap between PCS and ROME, is equally unhelpful”*. Hence, the investigation of the TIR dynamism in France requires to produce *ad-hoc* identification criteria. We contribute to the literature on the impact of TIR activities on economic development by both focusing on the specific context of Hauts-de-France and proposing a general method of identification of businesses related to TIR activities.

### 3. Context of the Research: The Voluntarist Policy of Hauts-De-France Region

We apply the method of identification of TIR-related businesses in Hauts-de-France, that is ranked 12th among 13 regions in terms of GDP per capital, but 5th in number of

inhabitants. Hauts-de-France is the second poorest French region and TIR has been involved in development of entrepreneurship and innovation programs to promote economic growth. Hauts-de-France has been a forerunner in setting up a proactive policy in favour of the TIR. The region, inspired by [38]'s vision, was committed to revitalisation to pursue its industry conversion by favouring "technological and social biodiversity". The objective of the TIR project, launched in 2013 and renamed rev3 in 2015, is to help the transition of economic actors through its support to public, private and citizens' initiatives. The various projects aim to promote connected cities and regions, smart transport, renewable energies, circular economy, the creation of social capital and education to the challenges this societal transformation. This policy translates in the support to and promotion of 5 strategic fields, called "pillars": transitioning to renewable energies, such as wind, solar, geothermal or hydro, developing positive energy buildings, producing energy storage systems, deploying an energy internet and sustainable mobility of people and goods. In addition to these fields, business models are being strengthened: circular economy, function-based product-service systems and energy efficiency [39]. This policy relies also on financial supports to the actor of the TIR and is the most intense in France. For instance, the Region has invested 650 million euros in TIR activities in 2021 to accelerate their development.

Focusing on this regional scale is also relevant with regards to the significance of the role of the territory in the development of sustainable economy [40–45], particularly regarding sustainable mobility of people and goods [46], function-based product-service systems [47] and circular economy [48]. Indeed, their developments rely on the cooperation between a sector or a market's stakeholders and on the intervention of a third party, particularly local public authorities [45].

#### 4. Materials and Methods

The methodological approach relies on massive data collection in order to establish distinctive characteristics of the firms involved in the TIR. The data collection is then recursive and iterative. The data generating process encompasses 3 stages. The first stage aims at delimiting the set of firms involved in the TIR activities. We combine internet webscraping and text-mining on data bases of the Regional Council Hauts-de-France in order to capture these specific firms in a large and non-discriminatory sample. The second stage focuses on the collection of legal information from the firms related to the TIR. This information is the input of the third stage. This latter stage focuses on the estimation of the yearly employment of the firms selected to assess the regional trend of the TIR. The interest of this approach relies on the traceability of the firms, since a detailed list of business units results from the data collection. By contrast with macroeconomic and sectorial simulations, our approach is more prudential because it focuses only on the direct and observable employment. Indirect and induced employment are excluded.

##### 4.1. Stage 1: Limiting the Set of TIR Activities and Identification of the Firms

Most of the data results from internet webscraping and text mining on Regional Council data bases. We also survey professional associations and business clusters to obtain firms lists for each TIR activity. The method of webscraping consists in massive data collection from the internet. Our purpose is to collect specific lists of firms involved in TIR activities in Hauts-de-France. We collect data from 53 sources ranked and categorized given their TIR activity and their relevance (cf. Appendix A-Table A1). The sources are selected with the support of the Mission rev3, the Regional Department of TIR, the Chamber of Commerce and Industry, Ademe, *Hauts-de-France Innovation Development* and the "*Chaire des Explorateurs de la Transition*". We surveyed 40,788 observations including 5546 strongly specialized in TIR activities.

Thanks to the support of the *Centre d'Etude d'Aide à la Décision (CEAD) de Hauts-de-France Innovation Développement (HDFID)*, we perform identification of the firms based on text-mining on the firms' descriptions in the *Applications et Services de Travail en Réseau pour l'Innovation et le Développement Economique (ASTRIDE)* data base. We select the keywords

listed in Appendix A-Table A2 in collaboration with the stakeholders involved in the selection of the sources for the webscraping data collection, *Fonds Régional d'Amplification de la Troisième Révolution Industrielle* (FRATRI) 2020 and Ademe services. As with the webscraping approach, the interest of the text-mining is to identify and propose criteria for the classification of the firms in TIR activities. We have collected 8803 firms on ASTRIDE including 4723 strongly specialized in the TIR.

#### 4.2. Stage 2: Collection of Legal Information

Legal information is required to obtain the number of employees and the financial statements of the firms in financial data bases Diane+ Bureau Van Dijk. At the end of the first stage, 10,159 firms (20 percent of the sample) are not documented. We perform automatic requests on [49–51]. Requests are based on the name of the firms and additional information such as city, phone number and national industry sector classification. At the end of this second stage, 5709 observations over the 49,591, that is to say 11.51 percent of the sample, remain without legal information and cannot be included in the third stage. Nonetheless, it is likely that many of them already taken into account since 34.51 percent of the observations have multiple occurrences. These multiple occurrences in the selected sources are a desirable outcome insofar as it informs on the exhaustiveness of the sample and the strength of the link of the firm with the TIR activities. Since Diane+ provides information on the parent business units of the firm, the number of observations increases to 152,351, but results are only analysed for the “mother house” for which the information is the most complete.

#### 4.3. Stage 3: Data Collection and Estimation of Employment

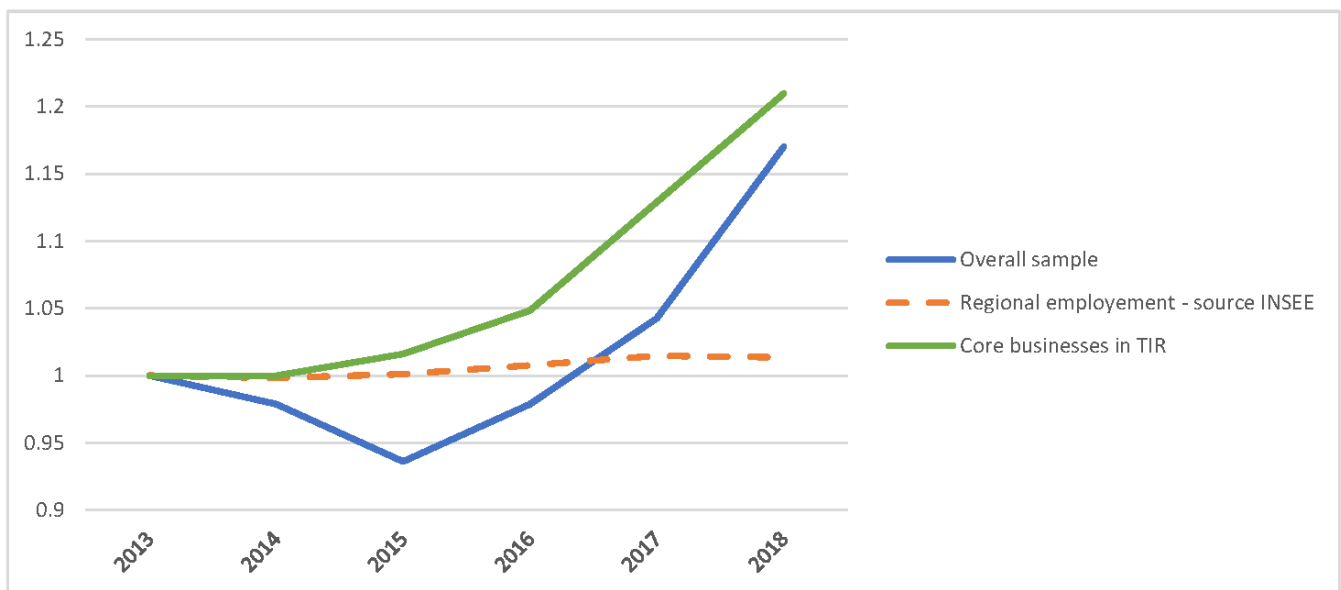
Two kinds of data are downloaded from the financial databases Diane+ and Astrée provided by Bureau van Dijk: data on the number of employees and standardized accounting statements from 2013 to 2018. When the number of employees is not available, we refer to OLS estimates. We predict the number of employees of the firm with the following regressors: the (i) total salaries in euros and the related (ii) benefits paid by the firm. (iii) The total value of assets reflects the size of the firm likely to modify the distribution of the wages. The (iv) industry sector and (v) period fixed effects are captured by categorical variables. Estimations are performed over 28,309 observations for which the number of employees is documented. We infer the predicted number of employees with accounting data for the rest of the sample. Following INSEE analyses, we assess the average growth in employment relative to 2013 with the end-sizing approach after controlling for modification in the structure of the sample [52]. Results are classified given the TIR activities, the department and for the samples of large and specialized firms.

## 5. Results

### 5.1. Employment Growth Related to the TIR in Hauts-De-France

Figure 1 shows the evolution of employment growth in Hauts-de-France in index with fixed base 2013 adjusted to sample attrition. The green and blue lines respectively reflect the evolution of employment in firms with a core business related to the TIR and in our overall sample. These values should be seen in the context of the general employment situation in Hauts-de-France over the same period, shown in the orange dashed line. We find that firms involved in the TIR strongly favour employment dynamics; this result is even more acute for firms with a core business related to the TIR. It is noteworthy that the slowdown observed between 2013 and 2015 in the overall sample can be attributed to the decline in the building and construction industries. As we can observe, employment raised from 2016 partly due to the change in the sample composition. Despite this end-of-period overestimation inherent to this approach, it is worth reminding that our estimation of employment growth is prudential, as only direct job creation is included. Direct employment in firms who did not file their accounts, indirect employment and induced employment are excluded.





**Figure 1.** Evolution of employment growth related to TIR in Hauts-de-France between 2013 and 2018 (in base 100 in 2013).

Table 1 shows the evolution of employment growth in firms with a core business related to the TIR and in our overall sample in volume and percent variation compared to the regional situation. We can observe a creation of +26,783 jobs in Hauts-de-France between 2013 and 2018, i.e., a growth of 1.34 percent for all sectors combined. Over the same period, organisations related to the TIR seems to have provided for up to 52,173 new jobs, of which 27,838 were created by firms strongly focused on the TIR activities.

**Table 1.** Estimation of direct employment growth from 2013 to 2018.

Firms with Core Business Related to the TIR		Overall Sample		INSEE Hauts-De-France—All Sectors <sup>1</sup>	
Jobs	% Var	Jobs	% Var	Jobs	% Var
+27,838	+21.09%	+52,173	+17.38%	+26,783	+1.34%

<sup>1</sup> Net of job destruction. Source: [53].

### 5.2. Dynamics by Pillar and across Districts

In Table 2, we present the distribution of firms by pillar and districts. The distribution of pillars is illustrated in Figure 2 and Table 3. The distribution of pillars across districts is homogenous. Data collected with our census is in line with the business demographics compiled by the INSEE over the same period. Nord concentrates 42 percent of businesses, Pas-de-Calais 23.8 percent, Oise 13.4 percent, Somme 11 percent and Aisne 9.9 percent. The firms listed fall for the most part into the strategic fields of the transition to renewable energies and the development of positive energy buildings that respectively account for 17.9 percent and 29.36 percent of firms listed. Table 4 shows that, on average, Pillar 1 firms are active in 2825 pillars and that only 2.59 percent of them are exclusively focused on Pillar 1 activities. It is surprising that 69 percent of Pillar 1 firms are also active in Pillar 2 activities, which indicates that these technologies are interrelated. A third of these firms are also active in Pillars 6 and 8. Pillars 1 and 5 are also better represented in the sample of specialised firms than in the overall sample.

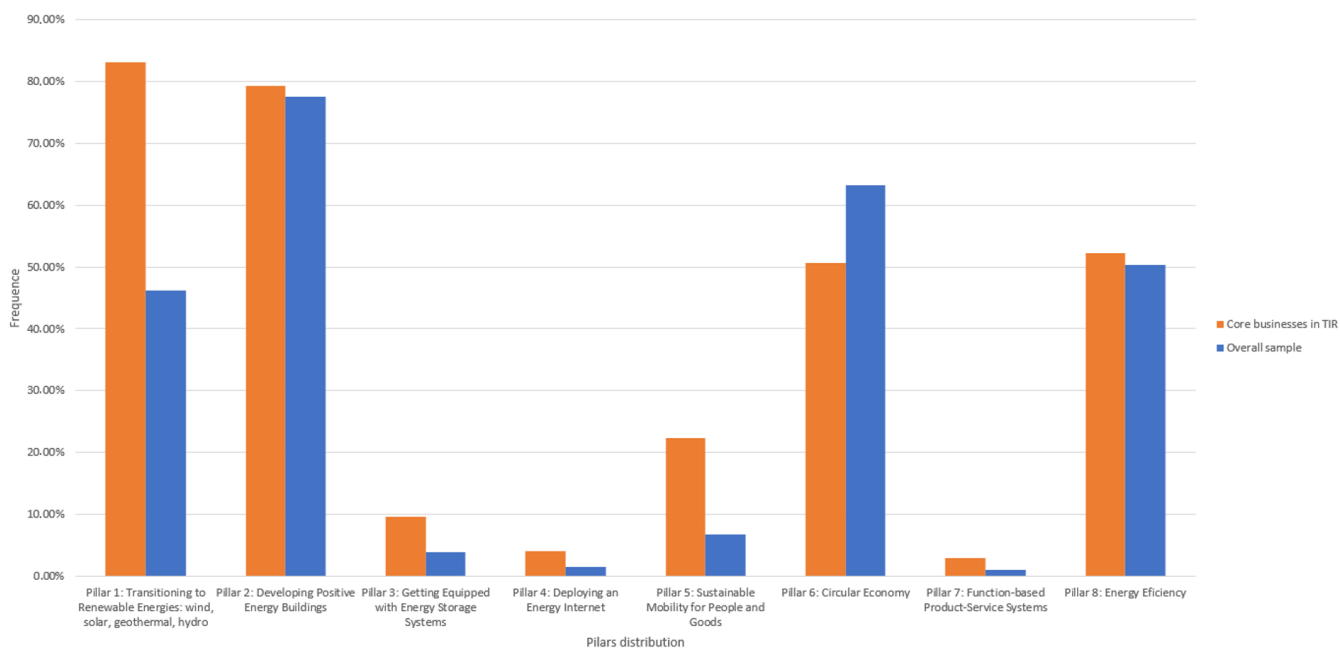


**Table 2.** Distribution of firms by pillar and districts.

Districts	<b>Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro</b>	<b>Pillar 2: Developing Positive Energy Buildings</b>	<b>Pillar 3: Getting Equipped with Energy Storage Systems</b>	<b>Pillar 4: Deploying an Energy Internet</b>	<b>Pillar 5: Sustainable Mobility for People and Goods</b>
Nord	17.99%	28.33%	2.71%	1.67%	5.14%
Pas-de-Calais	19.67%	29.54%	2.05%	0.93%	3.26%
Oise	16.62%	30.12%	0.53%	0.53%	1.71%
Aisne	16.19%	31.11%	0.79%	0.73%	2.02%
Somme	16.82%	30.26%	0.91%	0.96%	2.58%
Region	17.90%	29.36%	1.86%	1.16%	3.62%

Districts	<b>Pillar 6: Circular Economy</b>	<b>Pillar 7: Function- based Product- Service Systems</b>	<b>Pillar 8: Energy Efficiency</b>	<b>Total— Authors’ Calculation</b>	<b>Distribution of Firms— INSEE</b>
Nord	25.22%	1.44%	17.51%	42%	45%
Pas-de-Calais	25.54%	0.83%	18.19%	23.8%	21.4%
Oise	28.53%	0.42%	21.53%	13.4%	14%
Aisne	27.24%	0.64%	21.28%	9.9%	9.1%
Somme	27.04%	0.75%	20.67%	11%	10.5%
Région	26.15%	1.00%	18.96%	100%	100%



**Figure 2.** Distribution of activities and employment growth rates from 2013 to 2018.

**Table 3.** Table of contingency of number of firms by pillar.

	<b>Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro</b>	<b>Pillar 2: Developing Positive Energy Buildings</b>	<b>Pillar 3: Getting Equipped with Energy Storage Systems</b>	<b>Pillar 4: Deploying an Energy Internet</b>	<b>Pillar 5: Sustainable Mobility for People and Goods</b>	<b>Pillar 6: Circular Economy</b>	<b>Pillar 7: Function-Based Product-Service Systems</b>	<b>Pillar 8: Energy Efficiency</b>	<b>Average Annual Number of Firms 2013–2018</b>
Pillar 1	100%	96%	9%	1%	3%	36%	1%	38%	3,601
Pillar 2		100%	5%	1%	1%	64%	1%	64%	4,735
Pillar 3			100%	16%	17%	36%	11%	25%	458
Pillar 4				100%	86%	31%	75%	38%	131
Pillar 5					100%	18%	16%	10%	702
Pillar 6						100%	1%	75%	4,217
Pillar 7							100%	33%	104
Pillar 8								100%	2,618

**Table 4.** Pillar distribution of direct job creation from 2013 to 2018.

<b>Pillars</b>	<b>Firms with Core Business Related to the TIR</b>		<b>Overall Sample</b>	
	<b>Jobs</b>	<b>% Var.</b>	<b>Jobs</b>	<b>% Var.</b>
Pillar 1	+15,894	25.65%	+21,944	16.48%
Pillar 2	+8357	14.78%	+10,362	7.29%
Pillar 3	+2618	8.97%	+2556	8.66%
Pillar 4	−243	−1.43%	+88	0.51%
Pillar 5	+7167	8.55%	+7277	8.68%
Pillar 6	+17,208	21.17%	+25,048	11.30%
Pillar 7	−1376	−8.97%	−1073	−7.04%
Pillar 8	+6179	16.39%	+1579	2.86%
Total without duplicates	+27,838	+21.09%	+52,173	+17.38%

The cross-sectoral fields that are defined as economic models in rev3 benchmark rate similarly well. Businesses involved in circular economy account for 26.15 percent of the companies listed and the field of energy efficiency accounts for 18.96 percent of the sample. The other fields are conversely largely under-represented, either because they are at an embryonic stage, as for the deployment of an energy internet, or because of the difficulty of identifying which businesses develop operations in some branches of activity, particularly function-based product-service systems.

#### 5.2.1. Analysis of the Dynamics for Each Pillar

For each pillar, employment growth is derived in terms of volume over 2013 to 2018 and in terms of initial job quantity in 2013. Table 4 shows that employment dynamics differ from one pillar to the next. Activities related to transitioning to renewable energies (Pillar 1) and to developing positive energy buildings (Pillar 2) are largely represented in the sample. They generated a creation of +16.48 percent and +7.29 percent jobs respectively. Fields that are under-represented, and particularly “getting equipped with energy storage systems” (Pillar 3), are also growing strongly (+8.66 percent). Pillar 5 (sustainable mobility for people and goods) shows a similar growth rate but is abnormally under-represented with regards to the importance of the transportation industry in Hauts-de-France [54]. This

under-representation results from the difficulty of identifying sustainable businesses in the transportation industry. Among the cross-sectoral pillars, circular economy (Pillar 6) and energy efficiency (Pillar 8) are particularly dynamic with growth rates of 11.30 percent and 2.86 percent observed in the overall sample. However, these dynamics are stronger for companies with a core business directly related to the TIR. In that regard, energy efficiency (Pillar 8) is marked by a growth rate of 16.38 percent. The trend showed for companies with a core business related to the TIR is twice as strong as for the overall sample in the fields linked to Pillars 2, 6 and 8.

### 5.2.2. Analysis of the Dynamics across Districts

In Table 5, we reported employment dynamics related to the TIR across districts. Regarding job creation, Nord and Pas-de-Calais display stronger dynamics than the South of the region, because of their initial job quantity in 2013 and of the scale of their growth rates.

**Table 5.** Direct job creation by district in Hauts-de-France from 2013 to 2018 <sup>1</sup>.

Districts	Firms with Core Business Related to the TIR		Overall Sample	
	Jobs	% Var.	Jobs	% Var.
Nord	40,196	24.57%	54,864	8.27%
Pas-de-Calais	31,935	24.18%	45,637	11.01%
Oise	7900	10.89%	−589	−0.25%
Aisne	6542	13.95%	12,014	9.23%
Somme	–	–	–	–

<sup>1</sup> Depending on the number and distribution of firms on the territory, the same business can be listed in several districts. It is impossible to derive regional employment from the sum of employment in each of the region's districts.

We can observe that information related to firms in Somme lacks sufficient data to provide reliable identification of job opportunities in this district. This lack results from voluntary failure from firms to disclose information. The ASTRIDE data base of the Regional Council Hauts-de-France, devoted only to firms located in the former Nord-Pas de Calais territory until 2018, also reports a small number of firms for this district.

## 6. Discussion

The purpose of this article is to report on job creation generated by the TIR in Hauts-de-France. Our methodological approach enables the listing of firms related to the TIR in view of their analysis. To our knowledge, no previous research has examined the employment dynamics linked to the TIR through microeconomic modelling. We estimate net first job creation linked to the TIR from 2013 to 2018 at +52,173 for a growth of +17.38 percent, while the region counted a mere +26,783 jobs created for a growth of +1.34 percent. The proportion of TIR-related employment in Hauts-de-France would amount to 6.7 percent, i.e., 159,000 jobs. We can observe that this positive trend is stronger for firms classified as “specialised firms”, i.e., as having a core business related to the TIR, with a growth rate of +21.09 percent or 0.805 job created per business per year. The ANOVA test confirms the difference between the two groups (F-value = 2.295 \*\*, *p*-value= 0.0076). This result confirms the link between the development of the TIR and job creation established by academic [8,12,21,29,30] and grey literature [16,17,55].

The study of the dynamics by pillar shows that this strong growth is essentially supported by the transition to renewable energies, the development of positive energy buildings, circular economy and energy efficiency. The dynamism of the field of renewable energy is materialized also by the change in energetic mix. The production of renewable energy was 21.2% in 2019 whereas it was 4.2% in 2013. It substituted partly nuclear production which drop from 80% to 60% in the same period (See [56]). This suggests that these job concerns the emergence of new skills [33]. In the field of circular economy, there is a particularly significant difference between specialized firms (+16.39 percent) and the

overall sample (+2.86 percent). Only firms focused on the fields of energy internet and function-based product-service systems register job destruction. However, these fields are ill-represented in our sample. Surprisingly, the field of sustainable mobility is also under-represented, as Hauts-de-France is considered the third leading region for logistics in France [54]. The main difficulty lies in the absence of criteria differentiating sustainable logistics companies from traditional ones. Examining the distinguishing features of firms involved in sustainable mobility is required to better target censuses, as, following [57], representations of sustainability remain absent or fragmentary among the actors of the sector, all the more so as they cover different realities, depending on the nature of goods and actors concerned [40].

Results also reveal the importance of the local context [40,41,58]. This growth in employment is intrinsically related to the voluntarism of the regional authorities in supporting TIR. Remaining that the Hauts-de-France owns the second biggest nuclear power plant in Europe, the development of renewable energies especially wind energy has only been possible by the public investment and active cooperation with the firm in charge of the production and distribution of electricity. Another evidence of the importance of the local context is observed in the territorial differences. The dynamics by district shows that job creation is stronger in Nord and Pas-de-Calais, which constitute the historical region until 2015. They have benefited to the TIR policy in the early 2010, while the other districts Somme, Oise and Aisne were involved during 2015. These latter districts less exposed to TIR policy exhibit lower rate of growth. The dynamics is uneven in Oise: specialised firms increased employment by +10.89 percent while the overall sample shows sluggish growth (−0.25 percent). We advocate for more contextual analysis of the growth triggered by the TIR. Political and technological contexts set the economic growth potential of the TIR and the sources and the composition of new jobs (conversion, entirely new skills or expansion of existing jobs).

This research provides also a general method of identification of firms related to TIR activities. As many countries, France do not provide green or transition related classification of jobs contrasting with US or Scotland [2]. The bigdata based approach permit to both identify a large number of organizations involved in the TIR, but also to focus on specific subset of more dynamic business unit. It fosters the analysis of alternative metrics of the development of the TIR as well as the growth in fundraising, economic value added or turnover. It is also appropriate to understand the determinants of the success of these organization. Nonetheless, at this stage the method cannot capture precisely the nature and quality of the jobs without combining complementary data collection.

If employment growth is a sign of economic performance, it cannot account for the employment dynamics of the TIR on its own. Further research to investigate the quality of employment [52,59] is needed in order to foster a fair shift to a greener economy [60]. Some questions, such as *“Are these jobs new occupations, changing occupations or occupations developing from pre-existing jobs already linked to the TIR? Is the dynamics inclusive?”* require consideration [2,33,41] to promote understanding and support of the TIR activities. Although there is no unanimously accepted definition of green jobs or TIR today, the identification of skills required by the firms and the quality of jobs created is a question to address to better direct support and to improve the characterisation of the dynamics [33]. A more detailed description of the employment dynamics related to the TIR would require a comparison of the dynamics of shifting actors to that of their competitors who are not involved in sustainable activities. The outcomes of this detailed comparison would contribute to singling out the dynamics specifically related to the TIR in Hauts-de-France, to understanding which business models are attached to these organisations, and to providing local public authorities with decision-making tools. There is a need to mobilize multiple research designs, in particular those based on the collection of primary data, in order to reference this dimension of TIR-related employment. In addition, job creation cannot account for all economic dimensions of the TIR. Other dimensions would require further analysis to measure the success of these firms. Their survival rate, their profitability, the

amount of funds raised, or their innovation potential would provide a more acute view of the economic development of the TIR [44].

## 7. Conclusions

The purpose of this research is to report on job creation related to the TIR in Hauts-de-France from 2013 to 2018. The proactive policy of Hauts-de-France Regional Council in favour of the TIR since 2013 has fostered a unique context where networks and organisations in charge of the shift are prominent, facilitating the identification of the firms focused on the TIR activities. The originality of our approach is its use of the firms' individual data to facilitate monitoring of the dynamics over time and help targeted interventions from researchers wishing to further explore the profile of these organisations as well as from public authorities involved in supporting and guiding firms in shifting.

We collected a sample of 49,591 entities with their headquarters in Hauts-de-France and established distinctive characteristics of the firms involved in the TIR to create two groups: a large sample of 26,771 firms and a sub-sample of 6403 firms with a core business related to the TIR. Our results show the strong and positive employment dynamics in firms focused on the TIR with an average employment growth rate of +17.38 percent in a context of weak regional growth (+1.34 percent). This trend is amplified for the specialised firms with an increase of +21.09 percent. This growth in employment arises mainly from the fields of the production of renewable energies, positive energy buildings, circular economy and energy efficiency. These results support recent literature on the ability of the TIR at generating economic growth and confirm the importance of the political context in its development even we do not find differences in the composition TIR-related activities among districts.

While it is impossible to study the dimensions of spillover of the TIR entirely at this stage, our research forms a basis for broader and more critical research, particularly regarding the quality of employment created [2,33,59], in order to foster a fair shift to a greener economy [59,60]. Creating new criteria of recognition of firms focused on the TIR and accounting for other dimensions than created value, survival of firms and their degree of innovation in comparison to firms in more traditional sectors are but a few possible avenues for future research. These studies would contribute to better understand the factors fostering economic success of firms focused on the TIR in view of providing better support to their development without supplanting the aim of sustainability.

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## Appendix A

Table A1. Breakdown of sources by Pillar.

<b>Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro</b>	<b>Pillar 2: Developing Positive Energy Buildings</b>	<b>Pillar 3: Getting Equipped with Energy Storage Systems</b>	<b>Pillar 4: Deploying an Energy Internet</b>	<b>Pillar 5: Sustainable Mobility for People and Goods</b>	<b>Pillar 6: Circular Economy</b>	<b>Pillar 7: Function- Based Product- Service Systems</b>	<b>Pillar 8: Energy Efficiency</b>
Ademe Club International	Ademe Club International	Ademe Club International	Ademe Club International	Ademe Club International	Ademe Club International	Ademe Club International	Ademe Club International
Ademe-Projets Verts	Ademe-Projets Verts	Ademe-Projets Verts	Ademe-Projets Verts	Ademe-Projets Verts	Ademe-Projets Verts	Ademe-Projets Verts	Ademe-Projets Verts
					Ademe-Repair Café	Ademe-Repair Café	
Alice Alliance	Alice Alliance	Alice Alliance	Alice Alliance		Aquavaley	Club Noé	Alice Alliance
Annuaire Des Diagnostiqueurs Immobiliers	Cd2e	Aphypac	Cncres	Cncres	Eco-Circulaire.Org—Organisations Adhérentes	Cncres	Aquavaley
Aphypac	Enedis	Biogaz Valley	Enedis projets	Pexe	Fibois	Pexe	Biogaz Valley
Aquavaley	Fibois	Cd2e	Gimelec	Projets Rev3	Hydreos	Projets Rev3	Enedis
Biogaz Valley	Afcobois	Enedis projets	Greentech	Reseau Scic	Pexe	Reseau Scic	Fibois
Cd2e	Fédération Nationale Du Bois	Gimelec	Pexe		Projets Rev3		Gimelec
Cerrd	Greentech	Greentech	Pôle Energie Hdf		Rep-Gf—Liste Des Opérateurs Attestés		Greentech
Enedis	Pexe	Pexe	Pole Medee		Reseau Scic		Pôle Energie Hdf
Fimea	Pôle Energie Hdf	Pôle Energie Hdf	Projets Rev3		Sinoe		Pole Medee
Fédération Nationale Du Bois	Projets Rev3	Pole Medee	Reseau Scic		Syderep—Dbps		Projets Rev3
Gimelec	Qualibat	Projets Rev3	Pôlenergie-Adherents		Syderep—Dea		Qualibat
Greentech	Rge	Rs2e			Syderep—Emb		Unités De Méthanisation
Pexe	Reseau Scic	Reseau Scic			Syderep—Piles Et Accumulateurs		Atee Club Biogaz
Pole Dream	Team2	Ufe			Syderep—Pu		Energie2020
Pôle Energie Hdf	Cd2e Acteurs Eco-Construction	Unités De Méthanisation			Syderep—Rep-Deee		Pôlenergie-Methanisation



Table A1. Cont.

<b>Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro</b>	<b>Pillar 2: Developing Positive Energy Buildings</b>	<b>Pillar 3: Getting Equipped with Energy Storage Systems</b>	<b>Pillar 4: Deploying an Energy Internet</b>	<b>Pillar 5: Sustainable Mobility for People and Goods</b>	<b>Pillar 6: Circular Economy</b>	<b>Pillar 7: Function- Based Product- Service Systems</b>	<b>Pillar 8: Energy Efficiency</b>
Pole Medee	Cd2e Entreprises	Cd2e Acteurs Eco-Construction			Syderep— Vhu		Pôlenergie- Adherents
Projets Rev3	Cd2e Laboratoires	Cd2e Entreprises			Team2		Pefc
Rge	Pôlenergie- Adherents	Cd2e Laboratoires			Ufe		
Rs2e	Pefc	Energie2020			Upds		
Reseau Scic		Pôlenergie- Methanisation			Atee Club Biogaz		
Syndicat Energie Renouvelable		Pôlenergie- Adherents			Pefc		
Transition Ecologique Territoires Emplois							
Ufe							
Unités De Méthanisation							
Atee Club Biogaz							
Cd2e Acteurs Eco-Construction							
Cd2e Entreprises							
Cd2e Laboratoires							
Energie2020							
Pôlenergie-Methanisation							
Pôlenergie- Adherents							

Table A2. Key words used in the search on ASTRIDE—Hauts-de-France Innovation Développement.

<b>Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro</b>	<b>Pillar 2: Developing Positive Energy Buildings</b>	<b>Pillar 3: Getting Equipped with Energy Storage Systems</b>	<b>Pillar 4: Deploying an Energy Internet</b>	<b>Pillar 5: Sustainable Mobility for People and Goods</b>	<b>Pillar 6: Circular Economy</b>	<b>Pillar 7: Function- Based Product- Service Systems</b>	<b>Pillar 8: Energy Efficiency</b>
Renewal energies	Positive energy buildings	Energy storage	Energy Internet	Mobility of people and goods	Circular economy	Product- service system	Energy efficiency

Table A2. Cont.

<b>Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro</b>	<b>Pillar 2: Developing Positive Energy Buildings</b>	<b>Pillar 3: Getting Equipped with Energy Storage Systems</b>	<b>Pillar 4: Deploying an Energy Internet</b>	<b>Pillar 5: Sustainable Mobility for People and Goods</b>	<b>Pillar 6: Circular Economy</b>	<b>Pillar 7: Function-Based Product-Service Systems</b>	<b>Pillar 8: Energy Efficiency</b>
Energy efficiency	Energy consumption	excessive spare capacity	SMART NETWORK	Multimodal transport	“zero emissions”	Energy transition	Direct energy efficiency
Hydroelectricity	Thermal renovation	Production irregularity	Smart grids	“zero emissions”	“Adaptating to climate change”	Service Economy	Indirect energy efficiency
Energy system	Energy and environmental quality	“zero emissions”	Smart cities	“Adaptating to climate change”	“Alleviating climate change”		Ecodesign
Decarbonated	Passive house	“Adaptating to climate change”	Smart grid	“Alleviating climate change”	recycling		Rebound effect
Wind energy	Energy producing buildings	“Alleviating climate change”	Smart city	Carpooling	Ecodesign		Heating
Photovoltaic	Own energy consumption	Energy transition	Load management	Swift mobility	Energy transition		Lighting
Geothermal	Revegetation	Energy control	“zero emissions”	Intermodality	Waste		Compressed air
Hydraulic	Brownfield redevelopment	Green energies	“Adaptating to climate change”	E-mobility	Sustainable consumption		Energy transition
Renewable marine energy	Innovative waste management		“Atténuation du changement climatique”	“Alleviating climate change”	Sustainable production		Green activities
Biomass	Ecodistrict		Energy transition	Bike	Salvage		
Methanation	Bio-based materials		Green activities	Electric vehicles	Green activities		
Geothermal energy	EV charging infrastructure			EV charging infrastructure	Rejects		
Hydrogen	EVSE			EVSE	Sustainable supply		
Energy conservancy	Hydraulic storage			Connector terminals	life cycle assessment		
Green energies “zero emissions”	Compressed air storage méthanation			Energy transition Air pollution	LCA Bio-based		
“Adaptating to climate change”	“zero emissions”			Noise	Industrial ecology		

Table A2. Cont.

Pillar 1: Transitioning to Renewable Energies: Wind, Solar, Geothermal, Hydro	Pillar 2: Developing Positive Energy Buildings	Pillar 3: Getting Equipped with Energy Storage Systems	Pillar 4: Deploying an Energy Internet	Pillar 5: Sustainable Mobility for People and Goods	Pillar 6: Circular Economy	Pillar 7: Function-Based Product-Service Systems	Pillar 8: Energy Efficiency
“Alleviating climate change”	“Adaptating to climate change”			Green activities	Bioeconomy		
Heating	“Alleviating climate change”			biocarburants			
Heating	“Alleviating climate change”			biocarburants			
Lighting	Heating			bioéthanol			
Compressed air	Lighting			Mobility management			
Energy transition	Compressed air						
Green activities	Energy transition						
Heat pump	Energy control						
Solar	Green activities						
Waste heat	Energy saving retrofit						
Heat recycling	Wood						
Biogas							
Firedamp							
Wood							
Steel production gas							
Low carbon							

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