

Article

# Digitalization and Environmental Aims in Municipalities

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**Abstract:** Many municipalities express a wish to use digital technologies to achieve environmental aims. However, there is still a need for a better understanding of how this should practically be done, both among municipalities and among ICT developers. We have used workshops and literature studies to formulate technological abilities of digitalization. We use two EU directives that are relevant for municipal environmental goals and combine the activities that these directives indicate with technological abilities of digitalization, in order to formulate practical implementations of digital technology to help these activities and reach the directives' goals. We suggest that this method can be used for any municipal goal, as follows: (1) Identify the objective (in our case set by the EU-directives); (2) Identify what activities these points will require or generate; (3a) From a municipal viewpoint: Based on the results of 1 and 2, formulate and structure ideas of how digitalization can support the objectives and how those ideas can be implemented; (3b) From a provider's viewpoint: Investigate what digital solutions supporting 1 and 2 exist, or how existing services can be tweaked to support the objectives and explore how new digital solutions supporting 1 and 2 can be developed.

**Keywords:** European Union; EU directives; municipalities; environmental aims; environmental goals; smart city; smart sustainable city; digitalization; ICT4S

## 1. Introduction

The last couple of years, the notion of “smart city” and the potential for digital innovations to help achieve societal goals have gained increased interest in the areas of city planning, environmental protection and digital development. Digital technology and information and communication technologies (ICTs) have been identified as having good potential for developing and managing cities more energy-efficiently [1–4] and sustainably [5,6] and for supporting a more sustainable urban lifestyle [1,7,8].

While ICTs are spreading to different parts of the world, their applications and use tend to differ globally between places—regions, cities, countries—depending not only on devices and access but also on culture and governance [9]. These factors impact their implementation for smart sustainable city development [5], just as city challenges and assets do. It is also apparent that different stakeholders have different understandings of the challenge and how it should be tackled [5,8]. Therefore, it is important to support industrial actors in understanding what problems cities face so that they can direct their solutions towards these problems. On the other hand, if ICT is going to have the positive impact that it has the potential for, cities need to understand how to make best use of the technology in a particular context [3]. There is a need for better co-operation between the ICT sector and public authorities [4,10].

In the European Union (EU), common problems on national levels are reflected in common aims and goals set by the EU, as well as to some extent common regulations. The explicit goals are specific to EU countries, but based on conditions that EU membership countries share with many other countries with similar conditions in terms of industrialization and building standards. While EU directives set frameworks of guidelines for the EU member nations, the frameworks are then interpreted and implemented in each member's national legislation and impact municipalities, producers and other stakeholders.

This article aims to formulate a way of identifying digital solutions to environmental problems important for municipalities, as identified in EU directives. This is done with the purpose of providing support for developers and municipalities to find, create and choose digitally based solutions to support environmental objectives.

European cities differ somewhat in the aspects mentioned above [9] but they also share common traits with each other, as well as with cities in other industrialized countries. For example, energy use from housing, traffic congestion, air quality and waste management tend to be important in more or less all cities. Drawing from this, we suggest that although this paper is largely based on EU directives, it can be relevant also for many cities in non-EU countries.

## 2. Methods

To choose what environmental perspectives to take and to find emerging technologies applicable to the field, we held iterative workshops and meetings with representatives from industry and from municipal and regional administrations in and around Stockholm, Sweden. Those meetings were held every one to two months over half a year. Due to scheduling issues, sometimes the same workshop concept was held several times with different representatives, resulting in thirteen such meetings and workshops during a 7 months period. The industry was represented by three employees from Ericsson Research and one from the network department at Telia Sweden. The participants from municipalities were three employees from the City of Stockholm (one from the IT and innovation department and two from the Spatial Development Office) and two from Täby municipality (both from the environmental department), a suburb situated north of Stockholm. A full day workshop was also held at the regional growth and development department of the county council.

During the workshops, the participants tried different ways to approach the environmental responsibility of municipalities. Eventually, it was decided to use EU environmental directives as proxies for environmental targets. The argument for this was that EU directives affect municipalities in many different countries, which makes management of them interesting for an international audience. We identified four environmental EU directives:

- (1) Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe [11]
- (2) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy [12]
- (3) Directive 2008/98/EC, the "Waste Framework Directive," WFD [13]
- (4) Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012, the "Energy Efficiency Directive," EED [14]

Bringing all four directives into this paper is not possible for reasons of space. An initial check of the documents revealed that the two first Directives mainly were concerned with monitoring. We found that too narrow and therefore choose to focus on the Waste Framework Directive (WFD) [13] and the Energy Efficiency Directive (EED) [14], as we saw a wider range of ways that digitalization could be interesting for these directives.

Furthermore, for the purpose of this paper, we chose to limit our analysis to only parts of the two directives. For the EED, "energy use in building renovations" and "exemplary role of public bodies' buildings" were chosen, as they together provide different types of issues: both bureaucratic issues

of monitoring and carrying out energy efficiency measures. For the WFD, we concentrate on two parts of the waste hierarchy: “waste prevention” and “waste reuse.” We chose these for primarily two reasons. Firstly, these parts have not been as well explored as recycling, energy recovery and disposal, and municipal representatives in the project pointed at those as most interesting. Secondly, these two steps have a number of different applications, both those that seem very direct and those that are harder to connect with ICTs.

From the chosen directives, we selected articles that were closely connected to the municipality and were directly connected to digitalization. After deep-reading the directives, a literature review of scientific literature and political reports was conducted to see how the implementation of the directives had been discussed in other sources. This included both literature explicitly discussing the directives and literature that concerned their themes without relating them directly to the directives themselves. From these readings, we found a number of actions to be carried out to reach the directives’ goals.

As for digitalization (see Section 4), a team consisting of researchers from KTH, Telia and Ericsson identified technologies by gathering information from the Internet and different documents mainly produced by the two companies. We further discussed the way of defining digitalization with colleagues within computer science. This led to the formulation of the digitalization abilities in Section 4.

The actions indicated in directives and literature were then cross-read with the digitalization abilities to see how the abilities might be used to help realize the formulated actions.

Although using the municipality as a starting point for our work, this article does not focus on the actor perspective. According to the WFD, the municipality has the main responsibility for household waste, which motivates a municipal perspective on waste. However, several of the solutions we found need to be implemented in other parts of society, for example, in industry. There are also differences between countries regarding the importance of the municipal level. The question of actors and responsibilities is important but as a first step towards a more comprehensive understanding of digitalization for environmental issues, we have chosen to focus on digitalization as such, rather than on the actor.

We have not studied the actual effects of digitalization on the environment. Instead, we are looking at how the EU-directives can be supported. So, if the EU-directives are steering development in a more environmental friendly direction, then digitalization should support that.

### 3. Two EU Directives

A directive from the European Union is “a legislative act that sets out a goal that all EU countries must achieve” [15]. A directive sets up goals for the member states to reach but it is up to the individual countries to devise their own laws and formulate their own measures for reaching these goals. If the country already has rules according to the directive’s prescription, it does not have to adopt additional rules. The directive states when, at latest, it should be implemented in the member states.

#### 3.1. The Waste Framework Directive

The Waste Framework Directive (WFD) describes “waste” as “any substance or object which the holder discards or intends or is required to discard” [13]. The directive states that the primary objective should be that as little as possible enter the state of waste and includes two new recycling and recovery targets to be achieved by 2020: 50% preparing for re-use and recycling of certain waste materials from households and other origins similar to households and 70% preparing for re-use, recycling and other recovery of construction and demolition waste. As guidelines on how to achieve this, the WFD formulates an EU common waste hierarchy (see Figure 1). This is a priority ladder of how waste should be handled, unless life-cycle thinking (LCT) regarding a certain type of waste indicates that another course of action is more applicable.



Figure 1. The Waste Hierarchy [13].

The Directive requires that Member States adopt waste management plans and waste prevention programs. The directive also states that member states may take measures to extend responsibility to producers of a product in order to strengthen the prevention, reuse and recycling and other recovery of waste. The Member States should also encourage a product design adjusted in order to reduce their environmental impacts [13]. Municipalities of the EU membership countries are responsible for residents' household waste, except for what is included in producer responsibilities that the country implements.

As explained above, this paper focuses the first two steps of the waste hierarchy as shown in Figure 1. As municipalities tend to only have responsibility for consumer waste, we have chosen not to include waste minimization and reuse in the production process.

The first, waste prevention, means “measures taken before a substance, material or product has become waste, that reduce: (a) the quantity of waste, including reuse of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products” [13]. Reuse, defined as “any operation by which products or components that are not waste are used again for the same purpose for which they were conceived” [13], can be part of waste prevention. Preparing for reuse is explained as “checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be reused without any other pre-processing” [13].

Technically, because of the definition of waste explained above, “preparing for reuse” is a type of waste treatment, while reuse is a prevention measure. However, in practice these two measures are often interlinked. For example, in a EU Commission report on waste prevention [16], the following measures were identified as “preparing for reuse” if performed on waste but part of “reuse” and thereby waste-prevention if performed on non-waste:

- Straight reuse, possibly by someone else and/or in a different way
- Refurbishment and improvements
- Reparation
- Redeployment and cannibalization, where working parts are used elsewhere but broken parts are discarded
- Remanufacturing, which requires full treatment process to guarantee the performance of the finished object.

### 3.2. Energy Efficiency Directive

The Commission communication of 10 November 2010 on Energy 2020 places energy efficiency at the core of the Union energy strategy for 2020 and outlines the need for a new energy efficiency strategy to enable all Member States to decouple energy use from economic growth. The first paragraph of the Energy Efficiency Directive (EED), states its necessity: the “unprecedented challenges resulting from increased dependence on energy imports and scarce energy resources and the need to limit climate

change and to overcome the economic crisis. Energy efficiency is a valuable means to address these challenges" [14]. According to the European Commission Energy Efficiency Plan [17], the greatest energy savings potential lies in buildings and the second greatest in transport. Since only the energy used in buildings is included in the EED, we have chosen to look at the building sector and targets concerning building renovations.

The EED sets up a number of goal categories that the EU member nations are required to meet. The goal categories are (1) Efficiency in energy use, (2) Efficiency in energy supply, (3) Horizontal provisions and (4) Final provisions. This paper is restricted to looking at the first of those. *Efficiency in energy use* promotes the establishment of a long-term strategy for mobilizing investments in the renovation of the national stock of buildings, both residential and commercial and both public and private. It includes ten Articles and we are here discussing two of those: Article 4, Building renovation and Article 5, Exemplary role of public bodies' buildings.

#### 4. Digitalization

Brennen and Kreiss [18] argue that there is analytical value in distinguishing between "digitisation" and "digitalization." They call digitisation a material process, focused on converting analogue streams of information into digital bits. This is contrasted to digitalization, which is about social life's restructuring around digital communication and media infrastructures. We support those definitions and find them useful for highlighting the difference between the technological conditions necessary for digitally related societal change (digitisation) and the actual change (digitalization). The latter is increasingly referred to as digital transformation.

##### 4.1. Technological Abilities

For our purposes, we complement Brennen and Kreiss' definitions with a suggestion of four technological abilities central for the digital world: Sensing and acting, Connecting, Storing and Processing. We also give four examples of how those abilities are combined into systems: Internet of Things, Cloud computing, Artificial intelligence and Computer visualization. The group of abilities are aimed as a tool for understanding digitalization and as help when investigating how digitalization can support the EU-directives. Below follows a short description of the abilities.

###### 4.1.1. Sensing and Acting

A sensor is a device that can detect or measure a physical property and record, indicate, or otherwise respond to it. GPS-sensors are used to determine a position. An actuator is responsible for moving or controlling a mechanism or system, often acting on sensor data. Sensors are at the heart of Internet of Things, as described below. And the GPS-sensors, or other positioning sensors, are needed in positioning and navigation systems such as the satellite-based system GPS, "Global Positioning System." As stated by Pinder [19], GPS is now close to ubiquitous.

###### 4.1.2. Connectivity

Connectivity and various telecommunication networks are at the core of digitalization. There are many types of networks with different capabilities and connectivity is a rather generic term. In essence, it can be described as an ability to connect devices in order to transfer data back and forth, for example, via the Internet. The Internet is the global system of interconnected computer networks using Internet protocols to link devices. Some other examples of technologies for connectivity are the radio access network, such as the cellular (mobile) networks 3G, 4G and 5G, fibre optic networks and cabled ones.

One of the most important differences of connectivity now in contrast to a few decades ago is increased ranges for where it is available. To put it simply, this ability has become wireless. Late 2016 there were 7.5 billion mobile subscriptions globally. That number is forecasted to increase to about 9 billion by 2020, whereof 90% are predicted to be mobile broadband subscriptions [20]. Although

almost 90 % of all smart phone subscriptions globally are connected to 3G and 4G, GSM/EDGE is still the overall largest subscription category [20]. This is likely to change as 5G gain ground.

#### 4.1.3. Storing

Without the ability to store data, the use of collecting and transmitting data is heavily reduced. Storing can be done locally in for example, cell phones or laptops, or in the cloud, which typically means at some data centre. Just as with the previous abilities, storing is an area that has developed enormously.

#### 4.1.4. Processing

Processing power is needed to make something out of the data retrieved from a connected world. That processing power, or computing capabilities, can reside in the cloud, on local hardware, or in the human brain. Without digital processing power, we merely have data and are stuck with doing the calculations needed for making the data useful ourselves.

### 4.2. Combining the Abilities

The power of digitalization lies in combining the abilities described above and applying them to solve real world challenges without ignoring complexities. Moreover, by releasing and combining data and knowledge, systemic benefits can be achieved—if done right. There is a potential to generate benefits through new insights, systemic optimizations, efficiencies and understanding of inherent complexities et cetera. By not simplifying and ignoring complex cause and effect dependencies, sub-optimizations can be avoided and the full potential of digitalization reached. Below, we give four examples of how the abilities mentioned above have been combined into new systems with new capabilities.

#### 4.2.1. Internet of Things

The Internet of Things (IoT) can be defined as the Internet between physical devices, buildings and other items embedded with electronics, software, sensors, actuators and network connectivity, enabling these objects to collect and exchange data and acting upon it. Connected sensors and actuators are enablers of IoT and smart environments, as they provide the ability to act and sense. Ericsson [20] defines a connected device as “a physical object that has an IP stack, enabling two-way communication over a network interface” (p. 33).

#### 4.2.2. Cloud Computing

Cloud computing can be described as ways of providing shared computer processing and data storing resources to devices on demand. It enables ubiquitous access to a shared pool of configurable computing resources, such as storage, processing, applications, services and computer networks [21]. One of the most obvious benefits with cloud computing is the flexibility and scalability that comes with not having to own hardware or data centres and the ability to give otherwise simpler computer devices more advanced capabilities.

#### 4.2.3. Artificial Intelligence

Artificial intelligence (AI) is an advanced kind of processing. AI can solve problems by five main principles; search, pattern recognition, learning, planning and induction [22]. The ability to perform advanced analytics and take autonomous decisions can be enabled by different forms of artificial intelligence and allow for deep insights and autonomous functions.

Machine learning is often described as a sub-discipline of AI, focused on the AI being able to learn from fed data, rather than being told what to do [23]. Deep learning is a less explored part of the machine learning field, where a computer system is fed with a lot of data and uses it to make sense of other data and a smaller subset of machine learning techniques is applied with the ambition



of solving any sort of problem requiring “thought,” either human or artificial [23]. Navigation in self-driving cars, based on sensor data as input together with on-board analytics, is one example of a deep learning application.

#### 4.2.4. Computer Visualization

An important aspect in order to make data actionable for humans is visualization and other means of presenting data. Visualization is used to allow users to see, explore and understand information. It can be explained as using processing power to make, for example, sensing and acting, positioning, connecting and storing more intellectually available to humans through representing the data in some sensory way, usually visual.

Data visualization goes way back in time with, for example, maps representing how spatial places were located to one another. Today, information visualization and visual data mining can be useful for exploring large data sets [24,25], such as the large amount of data being generated and gathered via, for example, big data technologies and sensors. Humans with intact vision generally perceive visual attributes very well. Therefore many different data can be made easier to understand by “mapping” them to different visual attributes [26]. While visualizing data sets is nothing new, there is a range of new technologies allowing people to experience data in new ways, such as, augmented, mixed and virtual reality. Additional dimensions of representing data, like audio and haptics, can be added by utilizing more sensory modalities than only vision.

### 5. Digitalization, Waste Prevention and Reuse

In this section, we put together main points from the Waste Framework Directive (WFD) and scholarly literature with the abilities identified in Section 4 to see how the identified technological abilities that are the building blocks of digitalization can help working towards the main points of the WFD. We divide the section in three parts: Waste prevention, Reuse and preparation for reuse and finally a third section consisting mainly of a summary table. This is not entirely the same division as in the WFD (see Section 3.1) but gives a clearer outline of the paper.

#### 5.1. Waste Prevention

Waste prevention is handled in two different ways in the WFD. The first is through Changed consumption patterns and the second is through Upkeep and reparation. In the following, they are presented in one Section each.

##### 5.1.1. Changed Consumption Patterns

The WFD points out change in consumption patterns as necessary for waste reduction, as the increased consumption in Europe is one of the main causes for the increased waste flows [13]. Höjer et al. [27] define four ways that digitalization can reduce the environmental impact and resource use of consumption:

- substitute (doing something through a digital service instead of with a physical artefact)
- intensify (using things more intensely)
- improve efficiency (mainly relevant at production level and not included in this article)
- inform (to convince people to reduce environmental impact of their consumption).

Dematerialization is one of the more prominent ideas about how digitalization can contribute to a lower consumption of physical goods by substitution, partially replacing them with digital solutions [1,27]. An example of this is to consume streamed media instead of printed. An analysis of this shows that there is a potential environmental gain, but that it depends on how the printed respectively streamed media is used in practice [28]. Potential support from digitalization are through connectivity and ability to store data either in the cloud or locally, as they require a stable and fast connection for the user, as well as the ability to keep needed information stored and/or processed.

Sharing goods holds the potential of intensifying their usage, which could reduce the amount of physical goods consumed [27] and thereby the amount of waste generated. Sharing goods can signify both various forms of shared ownership, with several users of the same objects and passing on things between users, shifting ownership between them [29]. While sharing things is nothing new, digitalization simplifies matching of peers that do not know each other well beforehand. Economic theory has suggested that online platforms to connect buyers and sellers of second hand goods have the capacity to decrease waste generation through the second hand economy leading to lessened material flows [30]. It is also lifted as an example of waste minimization by the European parliament's guidance document [31]. The Nordic council of ministers have also published a report on environmental impacts of the sharing economy where they specifically look into transport, housing and smaller capital goods [32]. Key aspects from a digitalization point of view for sharing of goods are first of all connectivity and storage. To improve sharing services positioning can be useful as well as IoT where appliances can communicate directly to find a match between demand and supply.

Information, education, and awareness raising can be tools to uncover change [16,33], and are suggested by the European Parliament [31] as examples of waste prevention measures. Digital media—fundamentally based on connectivity, sometimes with cloud computing and elements of visualization—can be a good complement to traditional media for awareness campaigns about waste in general or targeting certain waste fractions [34,35].

As many municipalities already have online information on waste handling [8], this could include waste minimization. Another could be location based services and precise indoor positioning, enabling messages to be sent to users just in time on the right spot and contextually triggered messages. See also Table 1.

### 5.1.2. Upkeep and Reparation

There are some cases where ICTs might not be the main tool to help bring forth a change but can monitor implementation of other tools. A European commission report [16] proposes that regulatory and legal instruments are used to ensure waste minimization and that market-based/economic instruments can be used to influence behaviour towards waste-minimization, by influencing prices (e.g., with taxes) and quantities (e.g., with tradeable permit schemes). Here, ICT can play a role of informing how it works and be a valuable asset if permit schemes are implemented. It also suggests waste minimization with the help of eco-design, implemented through standards, education, information, financial support for research et cetera. Here, digital tools could be used for evaluating the eco-standard of a design. Digital databases can be used to provide examples and standards [16]. Connectivity can be used to collect big data from usage. The data can then be used in the development to make the products better adapted to true usage situations.

The WFD calls for extended producer responsibility, EPR, which puts part of the responsibility of the waste that a product produces on the producer. It could not only be useful to ensure that producers take responsibility after the product has entered the waste stream but also before, in a waste-prevention measure. This could include telepresence diagnostics and possibly eventually reparations, or at least maintenance. Sensors that report immediately if something is malfunctioning, or signal that it is time for maintenance, are already a reality. A dedicated development of the use of IoT for this kind of extended stewardship is plausible and could spread to more or less any goods.

Users can also be provided easily available and readily updated information and tutorials on how to best take care of their things, including electronic goods, and even repair them. While users are already now providing hardware reparation guides for each other, there are currently few producers that do the same. An exception to this is FairPhone, whose modular phones can be repaired at home and who also provide repair guides for the user online [36]. Online repair networks for household goods are also presented as an example of a suggested activity in a guidebook from the European Parliament [31]. A summary of activities and digitalization requirements are presented in Table 1.



### 5.2. Reuse and Preparation for Reuse

Digital technology could be used to tag products and packages to make them traceable. This way, producers can more easily be held accountable later or incentivize the collection of waste. With EPR, the producer will be held accountable for the environmental burden, pollution and depletion caused by the producing process but can also be asked to manage the impacts of a product during its life and at end-of-life [33]. Zaman & Lehmann [33] argue that it is not enough to legally and policy-wise introduce an EPR system but that its implementation needs constant optimization in order to be effective. While most EPR systems are focused on recycling, it could also be used to promote waste minimization and reuse. An example of this can be letting consumers trade in their old product for a producer-controlled second-hand reselling, such as with certain clothing brands and phone operators already today. For electronic products, connectivity and sensors can simplify tracking and managing. See also Table 1.

### 5.3. Summarizing Digitalisation and the Waste Framework Directive, WFD

In Table 1, we summarize the results regarding the WFD. The table consists of four columns. The first indicates the framework priority in question. The second column indicates an activity that can be done to support the framework priority. The third column is more detailed and describes a feature that can be supported by digitalization and the fourth and final column summarizes which technological abilities, see Section 4, can support the feature.

**Table 1.** Examples of the role of digitalization to support the Waste Framework Directive (WFD).

Framework Priority	Activity	Feature	Technological Abilities/Combination
Waste prevention/changed consumption patterns	Substitute	Streaming media External data storage and processing	Connectivity Storage Cloud services
	Intensify	Online system for sharing of goods Awareness raising through campaigns	Connectivity Storage Positioning IoT Connectivity
	Inform	Display of environmental effects Information available from municipality online	Computing Visualization Connectivity
Waste prevention/upkeep and reparation	Monitoring	Databases	Sensors Cloud services Visualization
	Extended stewardship	Telepresence diagnostics; automatic maintenance; auto-updates	Cloud services IoT
	Inform	Online tutorials	Cloud services
Reuse and preparation for reuse	Traceability	Tag products	Sensors Positioning Cloud Connectivity
	Extended producer responsibility	Producer-controlled second-hand markets	Storage Positioning IoT

## 6. Digitalization for Energy Efficiency in Public Buildings

In this section, we have selected the parts of the Energy efficiency directive (EED) that are most relevant for this article. The section consists of two parts—Section 6.1 on Building renovation (Article 4 in EED) and Section 6.2 on Exemplary role of public bodies' buildings (Article 5 in EED). In Tables 2 and 3, by the end of Section 6.1 respectively Section 6.2, we summarize the results from respective Section.

### 6.1. Building Renovation (Article 4 in the EED)

Government buildings may succeed less than residential buildings with energy efficiency measures, since government buildings will not be likely to plead to its users' sense of monetary economics using information; as the majority of them will be employees and do not pay the energy

bills themselves. On the other hand, housing inhabitants often fail to implement energy saving measures even when they would gain from it financially [37,38]. This suggests a potential role for interventions that is not based on price and financial savings but instead target behaviour directly with “nudging” [37,38]. We assume that this would also be applicable to government buildings.

According to Article 4 of the EED, all member states shall establish a strategy for investment in the renovation of the national stock of residential and commercial buildings, both public and private. That strategy shall encompass:

- “(a) an overview of the national building stock based, as appropriate, on statistical sampling;
- (b) identification of cost-effective approaches to renovations relevant to the building type and climatic zone;
- (c) policies and measures to stimulate cost-effective deep renovations of buildings, including staged deep renovations;
- (d) a forward-looking perspective to guide investment decisions of individuals, the construction industry and financial institutions;
- (e) an evidence-based estimate of expected energy savings and wider benefits ” [14].

In the following section, we discuss 4a and 4b in relation to digitalization. We do not directly discuss 4c–e, since they are not directly supported by digitalization.

#### 6.1.1. Article 4a: Create an Overview of the National Building Stock

The EED proposes to create an overview of the national buildings stock, of both public and private buildings, based on statistical sampling. The public sector should also “undertake a comprehensive and accurate inventory of its own building stock, including energy performance” [31] (p. 10).

Another alternative is to collect real-time information on energy use from all buildings with the use of connectivity, cloud technology and sensors as part of data collection from smart meters.

Visualization would be relevant for the overview. For example, a map based visualization can be used to illustrate the energy usage [39].

Building data, such as building usage, components, operating rules and maintenance activities, is often stored in a Building information model (BIM) [40]. Artificial intelligence can use building data together with data on weather, users, global heat loss coefficient and day types to formulate realistic estimations of the actual energy use [41].

#### 6.1.2. Article 4b: Identify Cost-Effective Approaches to Renovations Relevant to the Building Type and Climatic Zone

To identify best approaches of buildings it is needed to calculate energy savings and select optimal retrofit solutions. Virtual retrofit models apply artificial intelligence combined with BIM to create energy simulations and use multi-criteria decision support systems and virtualization to help understand possible outcomes [42].

To follow up the actual results, sensors as part of smart metering can collect data to be analysed automatically with the help of cloud technology and connectivity.

In Table 2, we summarize the results regarding building renovation in the EED. See Section 5.3 for an explanation of the table.

**Table 2.** Digitalization and building renovation in the Energy Efficiency Directive (EED).

Framework Priority	Activity	Feature	Digitalization Abilities/Combination
Article 4a: Create an overview of the national buildings stock	Data inventory	Read and register data on buildings' energy usage Store data where it can be accessed	Sensors Connectivity Cloud technologies AI Cloud technology
	Formulate realistic estimations of energy use	Show by visualizing data Make pattern recognitions from building data Collect real-time information	Data Representation Artificial intelligence Connectivity Cloud Technology Sensors
Article 4b: Identify cost-effective approaches to renovations	Calculating energy savings and selecting optimal retrofit solutions	Virtual retrofit models	Artificial intelligence Cloud Technologies Visualization
	Follow up results	Smart metering Automatic analysis	Sensors Cloud technologies Cloud technologies Connectivity

## 6.2. Exemplary Role of Public Bodies' Buildings (Article 5 in the EED)

Municipalities and other public authorities can have political incentives to be early adopters of new technology. And according to the EED, buildings owned and occupied by central government need to take an exemplary role in improved energy performance by “lead[ing] by example and implement[ing] well-planned, high-quality deep renovations” [14] (p. 10). Only buildings that are owned by the central government—normally the state—are technically bound to this part of the directive. However, according to article 5.7, the member states shall also encourage other public bodies, including at regional and local level, to conduct actions for energy efficiency in saving [14]. Therefore, we draw the conclusion that the EED still speaks for energy efficiency and energy saving at a municipal level.

### 6.2.1. Article 5.1–5.4: Yearly Renovations

Each year, 3% of the total floor area of heated and/or cooled central government buildings should be renovated to meet the minimum energy performance requirement for buildings larger than 250 m<sup>2</sup> [14]. The buildings with the poorest energy performance shall be prioritized. Part of achieving this could be gathering data on energy performance of the governments' building stock, using sensors together with BIM stored in the cloud. The renovations could also be visualized beforehand, both individually and with map-based visualization, to support decision-making, similarly as suggested for article 4b in Section 6.1.2.

### 6.2.2. Article 5.5: Inventory of Government Buildings

Member states must establish an inventory of heated and/or cooled central government buildings and make it publicly available. According to the EU Coalition for Energy Savings [43], this is relevant for the whole public sector, which should undertake “a comprehensive and accurate inventory of its own building stock, including energy performance and other relevant energy data.” This requires gathering data as well as making this data available. IoT technologies and cloud computing could be used to measure and store data on the energy use in the buildings. Data could also be made available and understandable by visualizations of energy use.

### 6.2.3. Article 5.6: Alternative Approach for Energy Savings

Article 5.6 suggests combining deep renovations with measures for behavioural change of occupants. According to Loviscach [44], this can be achieved through information, persuasion and advice (often referred to as nudging) or automation. According to Lehner et al. [38], there are four main types of nudging: “(1) simplification and framing of information, (2) changes to the physical environment, (3) changes to the default policy and (4) the use of social norms” (p. 168).

Digitalization can be used to make users aware of their energy use and as decision support tools [40]. This can be done in several ways—via traditional displays like monitors, as augmented reality, or analogously using real-world objects [45,46]. Digitalization enables collaboration, interaction through social media and knowledge sharing around energy efficiency and energy savings (Kramers, 2013), which support behavioural change. Moreover, digitalization enables real-time cues regarding energy use, especially through IoT. Visualizations of benefits of energy efficiency improvements in buildings can make it easier to understand the energy savings intuitively.

For automation, sensors and artificial intelligence are important (see, for example, [47]). Cloud technology can be used as part of analysing and processing the data dynamically in order to for example, send notifications when something needs to be acted upon. Connectivity is important for letting sensors, actuators and connected things in the home communicate with each other for increased efficiency.

#### 6.2.4. Article 5.7: Energy Management and Efficiency

The EED says that public bodies should be encouraged to adopt an energy efficiency plan and put in place energy management systems including energy audits. It also suggests using energy service companies and energy performance contracting for financing renovations [14].

Here again virtual retrofit models can be used to understand benefits of renovations and choose the right alternative, similarly as for article 4b in Section 6.1.2. This can also be used to support an energy management system with energy audits.

In models on “energy savings as a service,” the renovation costs are paid using monetary savings from reduced energy use in the renovated buildings. This often means that an investor installs energy saving equipment in a building and the building owner pays it off by paying their historical utility bills to the investor, where the difference between the historical utility bills and the new lower bills pay for equipment and profit [48]. This could be more accurately achieved by using sensors tracking the energy usage, as well as connectivity and cloud technology enabling calculating the monetary savings using real-time price data and sending the information to the renovation company so they know what to charge.

In Table 3, we summarize the results regarding exemplary role of public buildings in the EED. See Section 5.3 for an explanation of the table.

**Table 3.** Exemplary role of public buildings in the EED.

Framework Priority	Activity	Feature	Digitalization Abilities/Combination
Article 5.1–5.4: 3% renovated per year	Prioritizing buildings with poorest energy performance	Gathering data on energy perform. of public building stock Visualization to support decision-making	Sensors Cloud technology (BIM stored in cloud) Map-based visualization Positioning
Article 5.5: Inventory of heated and/or cooled central government buildings	Establish inventory Make inventory publically available	Gather data Make data available and understandable to the general public	IoT Sensor networks Connectivity Visualization of energy use
Article 5.6.: Alternative approach: measures for behavioural change of occupants	Information, persuasion and advice (nudging)  Automation	Make users aware of their energy use and provide decision support Data collection (sensors) and analysis to map behaviours Collaboration, social media and knowledge serving  Notification when something needs to be acted on  Efficiency improvements	Visualization Sensors Data analytics  Connectivity Data analytics Software/Systems for analysing and processing the data dynamically IoT

Table 3. Cont.

Framework Priority	Activity	Feature	Digitalization Abilities/Combination
Article 5.7a and b: Encourage public bodies to adopt an energy efficiency plan and put in place an energy management system including energy audits	Evaluating energy efficiency benefits	Virtual retrofit models	Artificial intelligence Cloud technologies Visualization
Article 5.7c: Use energy service companies and energy performance contracting to finance renovations	Energy savings as a service	Sensors	Connectivity Cloud technology IoT

## 7. Concluding Discussion

In this paper, we have explored how digitalization can be used to support environmental targets at the municipal level. We identified the four abilities Sensing and acting, Connecting, Storing and Processing as the basic building blocks of digitalization. They are powerful technologies as such and in different combinations, they can create higher-level systems such as Internet of Things, Cloud computing, AI and Computer visualizations.

We treated a group of important policy documents—EU-directives—as a kind of municipal environmental targets. The directives led us to focus on some very specific topics without making the analysis dependent on a specific municipality, ensuring international relevance.

This paper proposes a method for better using digitalization to reach environmental targets and makes a first attempt to show a systematic way of starting such an effort. Civil servants need to look for new digital opportunities and providers must approach the municipal targets. Three steps are needed for this:

- (1) Identify the objective (in our case the EU-directives). How are the objectives formulated in the directive? Here it can help to think in terms of Direct environmental improvement, Implementation of management principles or Monitoring, as described below.
- (2) Identify what activities these points will require or generate. What activities supporting the targets can be identified in academic literature and other relevant documents from public organizations? What activities are identified from other stakeholders?
- (3) (a) From a municipal viewpoint: Based on the results of 1 and 2, formulate and structure ideas of how digitalization can support the targets and how those ideas can be implemented. Then approach providers with the resulting ideas.  
(b) From a provider's viewpoint: Investigate what digital solutions supporting 1 and 2 exist, or how existing services can be tweaked to support the targets and explore how new digital solutions supporting 1 and 2 can be developed. Then approach the municipality with the resulting ideas.

Using digitalization to support targets is to a high degree a matter of attitude and this simple method is designed to support a better understanding between municipalities and providers. 3a and 3b above would ideally take place in cooperation but there may be issues of public procurement complicating that. The idea with the method is to create a kind of communication space between municipalities and providers, where problems and solutions can meet.

The EED has a strong focus on goals and objectives for the member states to reach. The actions included in the EED are focused on how the member states can work with formulating policies for reaching these goals. The WFD also includes goals and objectives but they are all centred on the waste hierarchy and the WFD focuses on the waste hierarchy as the central changing factor for the future and to achieving the WFD goals. While the EED concentrates on an aspect of environmental performance—in this case energy savings—rather than actions, the waste hierarchy essentially consists of the actions to reach the objectives. The EED does contain actions towards reaching its goals

but also includes numerous actions that mainly serve to monitor and control authorities, building companies, et cetera vis-à-vis the directive. From this, we have identified three types of objectives from the directives:

- Environmental performance (reduction of energy use)
- Implementation of certain principles of action (waste hierarchy)
- Monitoring important environmentally related features (building stock inventory).

There are many measures one can take that would support reduced waste and more efficient energy use but that are not included in the directives. They have not been studied here. Especially when it comes to the EED, there are many digitalization solutions that could improve energy efficiency but that do not easily connect to the directive. An example of this is smart metering and smart homes technologies that can be used to monitor and control electricity consumption in homes. The actual potential of this is debated with studies of contemporary use of smart metering indicating a reduction of energy use by up to 10 percent and highly dependent on the feedback mechanism. However, it has not been the aim of this paper to present a comprehensive set of digitalization techniques that can support environmental targets but to formulate a way of identifying digital solutions to environmental problems. We have highlighted the importance of specifying the target that is aimed at with the digital solution and emphasized that this can be useful both for a local authority and for developers. When other targets than those directly derived from the EU-directives are in focus, further digital solutions will be added.

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## References

1. Mitchell, W.J. *E-Topia: "Urban Life, JIM—But Not as We Know It"*; MIT Press: Cambridge, MA, USA, 2000; ISBN 0262632055.
2. GeSI. *SMARTer 2020: The Role of ICT in Driving a Sustainable Future*; Technical Report, A Report by The Climate Group on Behalf of the Global e-Sustainability Initiative; GeSI: Brussels, Belgium, 2012.
3. Kramers, A.; Höjer, M.; Lövehagen, N.; Wangel, J. Smart sustainable cities—Exploring ICT solutions for reduced energy use in cities. *Environ. Model. Softw.* **2014**, *56*, 52–62. [[CrossRef](#)]
4. European Commission. *A Digital Single Market Strategy for Europe. COM(2015) 192 Final*; European Commission: Brussels, Belgium, 2015; Volume 20.
5. Höjer, M.; Wangel, J. Smart sustainable cities: Definition and challenges. *Adv. Intell. Syst. Comput.* **2014**, *310*, 333–349. [[CrossRef](#)]
6. ITU-T. Smart sustainable cities: An analysis of definitions. Available online: [https://www.itu.int/en/ITU-T/focusgroups/ssc/Documents/website/web-fg-ssc-0100-r9-definitions\\_technical\\_report.docx](https://www.itu.int/en/ITU-T/focusgroups/ssc/Documents/website/web-fg-ssc-0100-r9-definitions_technical_report.docx) (accessed on 17 April 2018).
7. Hilty, L.M.; Aebischer, B. *ICT for Sustainability: An Emerging Research Field What Is Sustainability?* Springer: Berlin, Germany, 2014; ISBN 3319092278.
8. Ringenson, T.; Höjer, M. Smart City Planning and Environmental Aspects? In *Proceedings of the ICT for Sustainability 2016, Amsterdam, The Netherlands, 29 August–1 September 2016*; pp. 159–166.



9. Wilson, M.I.; Corey, K.E. Approaching ubiquity: Global trends and issues in ICT access and use. *J. Urban Technol.* **2011**, *18*, 7–20. [[CrossRef](#)]
10. Granath, M. *The Smart City—How Smart Can 'IT' Be?: Discourses on Digitalisation in Policy and Planning of Urban Development*; Linköping University Electronic Press: Linköping, Sweden, 2016; ISBN 9789176856987.
11. EU. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. *Off. J. Eur. Commun.* **2008**, *152*, 1–43.
12. European Community. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Off. J. Eur. Parliam.* **2000**, *L327*, 1–82. [[CrossRef](#)]
13. European Parliament and Council. *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives*; European Parliament and Council: Brussels, Belgium, 2008; pp. 3–30.
14. European Parliament. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency. *Off. J. Eur. Union Dir.* **2012**, 1–56. [[CrossRef](#)]
15. European Union. EUROPA—Regulations, Directives and Other Acts. Available online: [https://europa.eu/european-union/eu-law/legal-acts\\_en](https://europa.eu/european-union/eu-law/legal-acts_en) (accessed on 18 April 2018).
16. European Commission; Hoornweg, D.; Bhada-Tata, P. *Analysis of the Evolution of Waste Reduction and the Scope of Waste Prevention*; European Commission: Brussels, Belgium, 2010; ISBN 3200687053.
17. European Commission. COM(2011)109 Energy Efficiency Plan 2011. Available online: [https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/efficiency\\_plan\\_en.pdf](https://ec.europa.eu/clima/sites/clima/files/strategies/2050/docs/efficiency_plan_en.pdf) (accessed on 18 April 2018).
18. Brennen, S.; Kreiss, D. Digitalization. *The International Encyclopedia of Communication Theory and Philosophy*, 1. Available online: <https://doi.org/10.1002/9781118766804.wbiect111> (accessed on 18 April 2018).
19. Pinder, D. Dis-locative arts: Mobile media and the politics of global positioning. *Continuum* **2013**, *27*, 523–541. [[CrossRef](#)]
20. Ericsson. *5G Radio Access*. White Paper. Available online: <https://www.ericsson.com/en/white-papers/5g-radio-access--capabilities-and-technologies/white-paper---5g-radio-access> (accessed on 18 April 2018).
21. Mell, P.; Grance, T. The NIST Definition of Cloud Computing Recommendations of the National Institute of Standards and Technology. *Nist Spec. Publ.* **2011**, *145*, 7. [[CrossRef](#)]
22. Minsky, M. Steps toward Artificial Intelligence. *Proc. IRE* **1961**, *49*, 8–30. [[CrossRef](#)]
23. Marr, B. What Is The Difference Between Artificial Intelligence And Machine Learning? Available online: <https://www.forbes.com/sites/bernardmarr/2016/12/06/what-is-the-difference-between-artificial-intelligence-and-machine-learning/#6d6bf74a2742> (accessed on 18 April 2018).
24. Keim, D.A. Visual exploration of large data sets. *Commun. ACM* **2001**, *44*, 38–44. [[CrossRef](#)]
25. Keim, D.A. Information visualization and visual data mining. *IEEE Trans. Vis. Comput. Graph.* **2002**, *8*, 1–8. [[CrossRef](#)]
26. Mazza, R. *Introduction to Information Visualization*; Springer: Berlin, Germany, 2009; ISBN 9781848002180.
27. Höjer, M.; Moberg, Å.; Henriksson, G. *Digitalisering och Hållbar Konsumtion*. Available online: <https://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6675-8.pdf?pid=15239> (accessed on 18 April 2018).
28. Achachlouei, M.A.; Moberg, A. Life Cycle Assessment of a Magazine, Part II A Comparison of Print and Tablet Editions. *J. Ind. Ecol.* **2015**, *19*, 590–606. [[CrossRef](#)]
29. Schor, J. Debating the Sharing Economy. *Gt. Transit. Initiat. Essay* **2014**, 1–19. [[CrossRef](#)]
30. Fremstad, A. Does Craigslist Reduce Waste? Evidence from California and Florida. *Ecol. Econ.* **2017**, *132*, 135–143. [[CrossRef](#)]
31. European Parliament. *Guidance on the Interpretation of Key Provisions of Directive 2008/98/EC on Waste*; European Parliament: Brussels, Belgium, 2010.
32. Skjelvik, J.M.; Erlandsen, A.M.; Haavardsholm, O. *Environmental Impacts and Potential of the Sharing Economy*; TemaNord 2; Nordic Council of Ministers: Copenhagen, Denmark, 2017; ISBN 9789289351560.
33. Zaman, A.U.; Lehmann, S. Challenges and Opportunities in Transforming a City into a “Zero Waste City”. *Challenges* **2011**, *2*, 73–93. [[CrossRef](#)]
34. Davis, K.C.; Shafer, P.R.; Rodes, R.; Kim, A.; Hansen, H.; Patel, D.; Coln, C.; Beistle, D. Does digital video advertising increase population-level reach of multimedia campaigns? Evidence from the 2013 tips from former smokers campaign. *J. Med. Internet Res.* **2016**, *18*, 235. [[CrossRef](#)] [[PubMed](#)]

35. Farr-wharton, G.; Choi, J.H.-J.; Foth, M. Food Talks Back: Exploring the Role of Mobile Applications in Reducing Domestic Food Wastage. In Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: The Future of Design, Association for Computing Machinery (ACM), Sydney, Australia, 5–7 December 2014; pp. 352–361. [[CrossRef](#)]
36. Proske, M.; Schischke, K.; Sommer, P.; Trinks, T.; Nissen, N.F.; Lang, K.D. Experts View on the Sustainability of the Fairphone 2. In Proceedings of the 2016 Electronics Goes Green 2016+, EGG 2016, Berlin, Germany, 6–9 September 2016.
37. Allcott, H.; Mullainathan, S. Behavior and Energy Policy. *Science* **2010**, *327*, 1204–1205. [[CrossRef](#)] [[PubMed](#)]
38. Lehner, M.; Mont, O.; Heiskanen, E. Nudging—A promising tool for sustainable consumption behaviour? *J. Clean. Prod.* **2016**, *134*, 166–177. [[CrossRef](#)]
39. Howard, B.; Parshall, L.; Thompson, J.; Hammer, S.; Dickinson, J.; Modi, V. Spatial distribution of urban building energy consumption by end use. *Energy Build.* **2012**, *45*, 141–151. [[CrossRef](#)]
40. Kramers, A. ICT applications to lower energy usage in the already built environment. *Smart Innov. Syst. Technol.* **2013**, *22*, 127–135. [[CrossRef](#)]
41. Wang, Z.; Srinivasan, R.S. A review of artificial intelligence based building energy use prediction: Contrasting the capabilities of single and ensemble prediction models. *Renew. Sustain. Energy Rev.* **2017**, *75*, 796–808. [[CrossRef](#)]
42. Woo, J.H.; Menassa, C. Virtual Retrofit Model for aging commercial buildings in a smart grid environment. *Energy Build.* **2014**, *80*, 424–435. [[CrossRef](#)]
43. The Coalition for Energy Savings. *Top 20 Checklist for Strong Implementation of the Energy Efficiency Directive*; Online Guide to the EU Energy Efficiency Directive. The Coalition for Energy Savings. Available online: <http://eedguidebook.energycoalition.eu/checklist.html> (accessed on 18 April 2018).
44. Loviscach, J. The design space of personal energy conservation assistants. *PsychNology J.* **2011**, *9*, 29–41.
45. Katzeff, C. Engaging design for energy conservation. *Metering International Magazine*; 2010, pp. 62–63. Available online: <https://www.metering.com/regional-news/europe-uk/engaging-design-for-energy-conservation-in-households/> (accessed on 18 April 2018).
46. Katzeff, C.; Nyblom, Å.; Tunheden, S.; Torstensson, C. User-centred design and evaluation of EnergyCoach—An interactive energy service for households. *Behav. Inf. Technol.* **2012**, *31*, 305–324. [[CrossRef](#)]
47. Nguyen, T.A.; Aiello, M. Energy intelligent buildings based on user activity: A survey. *Energy Build.* **2013**, *56*, 244–257. [[CrossRef](#)]
48. Hilke, A.; Ryan, L. Mobilising Investment in Energy Efficiency: Economic Instruments for Low-energy Buildings. In *IEA Energy Papers*; No. 2012/10; OECD Publishing: Paris, France, 2012; Available online: <http://dx.doi.org/10.1787/5k3wb8h0dg7h-en> (accessed on 18 April 2018).



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