On the Social Shaping Dimensions of Smart Sustainable Cities: ICT of the New Wave of Computing for Urban Sustainability

Simon Elias Bibri[1]

NTNU Norwegian University of Science and Technology, Department of Computer and Information Science and Department of Urban Planning and Design, Sem Saelands veie 9, NO–7491, Trondheim, Norway

John Krogstie

NTNU Norwegian University of Science and Technology, Department of Computer and Information Science, Sem Saelands veie 9, NO–7491, Trondheim, Norway

Abstract

Visions of future advances in science and and technology (S&T) inevitably bring with them wide–ranging common visions on how cities as social fabrics will evolve in the future as well as on the immense opportunities and potential risks this future will bring. Situated within what is described as science of science, this study analyzes the nature, practice, and impact of ICT of the new wave of computing for urban sustainability as a form of S&T. Specifically, it probes the ways in which this form has emerged from a variety of perspectives, and why it has become institutionalized and interwoven with politics and policy—urban dissemination—within the defining context of smart sustainable cities. Also, it addresses the risks this form poses to environmental sustainability in the context thereof. To achieve these aims, an analytical and philosophical framework of Science and Technology Studies (STS) is adopted, which supports analyses and evaluations whose approaches are drawn from a variety of disciplinary and theoretical perspectives. The study shows that smart sustainable cities are produced by the socially constructed understandings and socially anchored and institutionalized practices pertaining to ICT of the new wave of computing for urban sustainability and thus medicated by ecologically and technologically advanced societies. Accordingly, these cities as a manifestation of scientific knowledge and technological innovation are shaped by and also shape techno–scientific, socio–cultural, and politico–institutional structures. Moreover, the study demonstrates that the success and expansion of ICT of the new wave of computing for urban sustainability and thus smart sustainable cities stem from the morphing power, knowledge/power relation, productive and constitutive force, and legitimation capacity underlying computing and ICT as science and science–based technology. These are, however, shown to pose risks to environmental sustainability. Hence, they need to be reoriented in a more environmentally sustainable direction, as they can not, as currently practiced, solve the environmental problems placed in the agenda of smart and sustainable cities as a holistic approach to sustainable urban development.

Keywords: Smart sustainable cities, ICT, computing, S&T, urban sustainability, discourse, construction, innovation, socio–technical, techno–urban, society, politics and policy

---

1 Corresponding author. Tel.: +47 4 519 7992. E–mail address: simoe@idi.ntnu.no

1. Introduction

The rapid advances in ICT enabled and fueled by the recent discoveries in computing have transformed the contemporary city by technologizing and computerizing it. The immense improvement in computing and ICT over the past half–century has shaped all parts of society (Kramers et al. 2014). Innovations in computing continue to demonstrate that there is tremendous untapped potential for harnessing the creative and disruptive power of ICT and leveraging it to transform the way the city functions and ultimately the way citizens live—by unlocking the transformational effects of ICT as an integrative and constitutive technology. Indeed, becoming part of the things to which it is applied and deeply embedded into the very fabric of the city, ICT embodies a morphing power manifested in shaping how we create, do, and revolutionize things in connection with almost every urban function, process, activity, and domain. Hence, there is an increasing recognition that ICT constitutes a promising response to the challenge of urban sustainability of our time. The underlying premise is that urban sustainability deals with the complex mechanisms and patterns involved in the interactions between environmental, social, economic, and physical subsystems of urban society, and how these interactions affect the challenge of urban sustainability, and emerging ICT is grounded in the application of the complexity sciences to urban systems and problems. Undeniably, urban sustainability has been instrumental in instigating and engendering major shifts in the core practices, primary operations, and central institutions of the city in response to the goals of sustainable development, a transformative process that has been fueled by the recent advances in ICT and the infiltration of computer intelligence into the processes and systems of the city. ICT can be further leveraged in the advancement of sustainable urban development (e.g. Shahrokni et al. 2015; Bibri and Krogstie 2016b). It has made it possible to approach a range of issues around urban sustainability from a whole new perspective (e.g. Batty et al. 2012; Al Nuaimi et al. 2015; Bibri and Krogstie 2016c)

Contemporary debate in urban and academic circles is increasingly focused on ICT and sustainability as well as their amalgamation. It has become necessary to find and apply more innovative solutions and more sophisticated approaches to sustainable urban development. Besides, the way cities can intelligently be planned and developed has been of fundamental importance for strategic sustainable development to achieve the long–term goals of sustainability. Put differently, ICT in its various forms (infrastructures, applications, services, and capabilities) is increasingly seen to provide unsurpassed ways to address a range of complex issues and challenges facing cities. In fact, ICT is already enabling cities in many parts of the world to remain sustainable and thus livable in the face of staggering urbanization, growing social mobility, and ongoing transformation. The planning of cities as complex systems towards sustainable development requires innovative ideas and advanced methods (e.g. Rotmans, van Asselt and Vellinga 2000). ICT and sustainability play a key role in smart sustainable urban planning (Bifulco et al. 2016; Bibri and Krogstie 2016a, c). In other words, ICT development and sustainability awareness has resulted in an opportunity to rethink the way we plan and develop cities (Höjer and Wangel 2015).

When discussing computing and ICT and thus smart solutions and ideas for cities, reference is made to the evolving concept of smart sustainable cities (e.g. ITU 2014; Kramers et al. 2014; Adams and El–Zaart 2015; Rivera, Eriksson and Wangel 2015; Höjer and Wangel 2015; Bibri and Krogstie 2016a). The use of this concept serves to substantiate the growing significance of ICT in enabling smart and sustainable cities to realize their potential by getting smarter as to improving their contribution to sustainability and rising to the pressures of urbanization. In fact, this concept has emerged as a result of a lack of, or very weak, connection between smart cities and sustainable cities, despite the proven role of ICT in supporting cities in their transition towards sustainability, especially in relation to the management and planning of urban systems (e.g. Kramers et al. 2014). In light of this, recent research endeavors have started to focus on how to improve smart city approaches as well as smarten sustainable city models (e.g. Murray, Minevich and Abdoullaev 2011; Batty et al. 2012; Kramers et al. 2014; Bibri and Krogstie 2016b)) by integrating the two perspectives as urban development strategies. This is an attempt to achieve the required level of operational functioning and planning in line with the goals of sustainable development. This holistic approach holds great potential to address the challenge of, or provide solutions for moving towards, urban sustainability (Batagan 2011; Murray, Minevich and Abdoullaev 2011). Therefore, the concept and development of smart sustainable cities has come to the fore, and is rapidly gaining momentum as a holistic approach to urban development and as an

academic pursuit, not least in ecologically and technologically advanced nations. Besides, we live in a world where computing and ICT have become deeply embedded into the very fabric of the city, i.e. its systems, processes, and functions are pervaded with computer intelligence and various forms of automation. It follows that it is high time for sustainable cities to smarten up and smart cities to get smarter in an increasingly computerized urban world. This is predicated on the assumption that advanced ICT offers tremendous potential for monitoring, understanding, probing, assessing, and planning the city, which can be leveraged in the advancement of urban sustainability.

The above discussion is positioned within the half–a–century debate over the role of science and science–based technology in modern society. Here the focus is on the role of computing and ICT as a form of science and technology (S&T) in advancing urban sustainability. S&T permeate contemporary urban debates, policy and politics, and are seen as key for solving environmental and socioeconomic challenges and problems facing the contemporary city. Concurrently, S&S are increasingly challenged by some scholars, often exposing risks of techno–scientific achievements in the context of the evolving urban development approaches. However, recent discoveries in computing and advances in its ICT applications have given rise to new socially disruptive technologies. Of more prevalence of such technologies, which also represent forms of pervasive computing, are Ubiquitous Computing (UbiComp), Ambient Intelligence (AmI), the Internet of Things (IoT), and Sentient Computing (SenComp) This is manifested in the emergence and dominance of ambient, sentient, ubiquitous, and Internet–of–everything cities (e.g. Böhlen and Frei 2009; Shepard 2011; Thrift 2014; Shin 2009; Kyriazis et al. 2014). Further, heralding a major technological change, such technologies and their amalgamation are projected to result in a drastic transformation of the technological ecosystem in all its complexity and variety. This will in turn alter how ICT can be applied and used in the city, in particular in relation to sustainable urban development. It has been suggested that as computing and ICT become pervasive, i.e., data sensing, information processing, and wireless communication networking become more and more embedded throughout urban systems and domains and citizens' objects, we can speak of cities getting smarter as to solving environmental, social, and economic problems as well as providing services to citizens to improve the quality of their life (Shepard 2011; Townsend 2013; Piro et al. 2014; Batty et al. 2012; Bibri and Krogstie 2016c). There is a growing recognition that the evolving techno–urban trend, which involves integrating various forms of pervasive computing in the city infrastructure, will bring about further transformational effects as to urban sustainability. This intellectual trend has come to be identified as the discourse of ICT of the new wave of computing for urban sustainability.This discourse has been instrumental in shaping the discourse of smart sustainable cities. The underlying premise is that computing and ICT has significant effects within the contemporary city. As advances of S&T, they are altering long–standing forms of city structures and amplifying existing city transformation models in terms of sustainability and what it entails in terms of the way the city functions and citizens live. Specifically, they are reshaping existing patterned urban arrangements and physical structures as well as ways of addressing the problems of urban sustainability and meeting its required level, which are emergent from and determinant of the actions of many urban actors. In the contemporary city, scientific innovation and its ICT applications are seen 'as indispensable for…bringing more advanced solutions for social, economic, and environmental problems and for providing new services to citizens.' (Bibri 2015b, p. 1) Indeed, major urban transformations are being promised upon the advent of ICT of the new wave of computing on the basis of ICT innovations that have been enabled by scientific discoveries in computing. Unsurprisingly, ICT of the new wave of computing is gaining increasing attention in the ambit of smart sustainable cities, attracting a lot of interest from research institutions, universities, industries, policy makers, and governments, owing to its role in the structural transformation of environmental, physical, social, and economic subsystems of the city. However, like all forms of S&T, ICT of the new wave of computing for urban sustainability is being questioned by some scholars in the context of smart cities and smart sustainable cities, often unmasking risks of techno–scientific achievements posed to environmental sustainability. In point of fact, city stakeholders are faced with great challenges when attempting to take advantage from the fascinating possibilities being offered by ICT of the new wave of computing for advancing sustainability. Bringing environmental values to the forefront of science–based technology in relation to smart sustainable cities signifies acknowledging that ICT that can be so disruptive is far from being harmless to nature and risk–free to the city, to draw on Bibri (2015b). In all, science–based technology opens up opportunities as well as poses risks.

3

On the basis of an approach to cross–disciplinary integration, this study analyzes the nature, practice, and impact of ICT of the new wave of computing for urban sustainability as a form of S&T. Specifically, it probes the ways in which this form has emerged from a variety of perspectives, and why it has become institutionalized and interwoven with politics and policy—urban dissemination—within the defining context of smart sustainable cities. Also, it addresses the risks this form poses to environmental sustainability in the context thereof.

This study consists of 5 sections. In Section 2, we outline the chosen analytical and philosophical approach of STS and the related methodological framework of discourse analysis, underpinned by a social constructionist worldview. Section 3 introduces, describes, and discusses the key relevant theoretical and conceptual constructs that make up this study. Section 4 presents the outcomes of the analytical and philosophical work, encompassing the diverse social construction and shaping dimensions of smart sustainable cities and how these dimensions interrelate and inform one another. It moreover includes the discursive–material dialectics of ICT of the new wave of computing for urban sustainability. Finally, we present our concluding remarks and discussions in Section 5.

2. STS Analytical and Philosophical Approach—Discourse Analysis Underpinned by Social Constructionist Orientation

This study probes how computing and ICT as advances in S&T directed towards advancing urban sustainability link up with other societal developments in such prominent spheres as culture, policy, politics, and ethics as well as ecological philosophy in the context of smart sustainable cities. Accordingly, it is positioned within the research and academic field of STS. As an analytical and philosophic approach, STS investigates the construction and role of S&T in society—in other words, the ways in which different forms of S&T emerge and evolve as well as become institutionalized and socially anchored—interwoven with policy and politics and thus disseminated at the macro level. In short, this approach examines S&T in its wider social context (e.g. Biagioli 1999; Jasanoff et al. 1995; Sismondo 2003; Hess 1997), i.e., 'the relationship between scientific knowledge, technological systems, and the wider socio–cultural system in which such knowledge and systems are embedded.' (Bibri 2015b, p. 19). Accordingly, ICT of the new wave of computing for urban sustainability is embedded in the socio–technical landscape of policy, politics, institutions, and environmental and social values that shapes smart sustainable cities within ecologically and technologically advanced societies. With its two main streams of scholarship as an academic field, STS involves research on the nature and practice of S&T and on the risks and other negative implications S&T poses to environmental and ethical values. In the context of this study, STS is concerned with examining the dialectic interplay between ICT of the new wave of computing for urban sustainability as a form of scientific knowledge and technological development and other societal dimensions, treating computing and ICT for urban sustainability as cultural and material productions as well as historical events. Historical analysis is beyond the scope of this study. In this regard, however, ICT of the new wave of computing for urban sustainability as a particular formulation and configuration of S&T represents social constructs and cultural frames built on the view of technologically and ecologically advanced societies at this time of history. Hence, it is approached as—which is applicable by extension to smart sustainable cities—a set of interrelated social institutions and structures possessing distinctive arrangements, constellations, regimes, strategies, discourses, as well as environmental commitments and professional allegiances that are specific to such societies as modern cultures, and that change over time. In other words, it is analyzed as socio–cultural and material practices that are shaped by societal factors (scientific, technological, institutional, urban, economic, cultural, and historical) in connection with smart sustainable cities as its defining context and thus a manifestation of a combination of science, science–based technology, sustainability science, and urban planning. And such practices represent a crucial basis for the reproduction of urban reality. In this study, STS entails a variety of disciplinary and theoretical perspectives, including sociology, cultural and communication studies, innovation studies, philosophy, policy and political studies, socio–technical studies, and environmental studies. In this sense, it involves the production, emergence, uptake, role, and impact of ICT of the new wave of computing for urban sustainability in the context of smart sustainable cities.

As to the methodological orientation of this STS study, the intent of the espoused framework ought to highlight scientific, technological, social, cultural, environmental, and philosophical perspectives in

relation to smart sustainable cities. Generally, STS employs diverse qualitative approaches, such as discourse analysis, comparative historical analysis, and cases and controversies, depending on the topic under investigation.This study adopted discourse analysis as a research methodology given the nature and scope of the topic under study. Here discourse analysis is considered as a deconstructive reading of a set of relevant documents, which inscribe themselves within the discourse of ICT of the new wave of computing for urban sustainability. Therefore, the analytical focus of this STS study is on the discursive–material facets and dialectics of smart sustainable cities as techno–urban transformations. Incidentally, the discourse of smart sustainable cities metonymically represents the discourse of ICT of the new wave of computing for urban sustainability. Another reason for adopting discourse analysis is that this STS study deals with (scientific) knowledge constructions and the societal context—ecologically and technologically advanced nations—in which such constructions are given both form and meaning and ultimately applied as practices, to draw on Bibri (2015b). Moreover, discourse analysis as a trans–disciplinary analytical strategy is employed here to examine how understandings of the link between ICT of the new wave of computing, sustainability, and urban planning, i.e., meanings pertaining to smart sustainable cities, are semiotically constructed and materially produced in their sociocultural context. More specifically, to probe the techno–urban visions of smart sustainable cities and their role alongside material mechanisms and practices in their translation into hegemonic techno–urban projects, initiatives, and strategies and, thus, their institutionalization in urban structures and practices within the increasingly computerized and data–centric cities of today, i.e., in reproducing and/or transforming urban domination with respect to sustainability. It is worth noting that making judgements about this version of analytical and philosophical account in relation to the phenomenon of smart sustainable cities can be done through referring to the environmental (and ethical) values embedded in the sociocultural context or evaluating the level of veracity and facticity. However, our discourse analysis methodology integrates several stands, drawing on a number of theoretical perspectives (e.g. Foucault 1972, 1991; Fairclough, Jessop and Sayer 2004; Fairclough 2005; Jessop 2004; Sum 2004, 2006).

In addition, discourse analysis is one of the most used analytical approaches in social constructionism for discourse is of fundamental importance for constructing social phenomena, categories, and mechanisms as shared understandings of the social world. Social constructionism deals with the ways in which such understandings are jointly constructed, reconstructed, institutionalized, and conventionalized by society, thereby constituting the basis for shared assumptions about reality. Accordingly, discourse analysis is underpinned by a social constructionist approach to knowledge, which rests on several premises, including historical contingency and cultural specificity of knowledge, critical approach to taken–for–granted (scientific) knowledge, the relationship between knowledge (and its discourses) and social practices as well as social processes (Gergen 1985; Burr 1995). For a descriptive account of the premises of social constructionism, the reader is directed to Bibri (2015b). Its main philosophical assumptions entail that multiple categories of reality are legitimate, written works are open to multiple readings, and language is not a representation of reality. Both Kuhn (1962) as a philosopher of science and Foucault (1966, 1972) as a sociologist of science adhere to the premises shared by social constructionist approaches, and their works were instrumental in establishing that scientific knowledge and related facts are not mere reflections or pure representations of reality—but rather outcomes of socio–culturally conditioned investigations.

3. Conceptual and Theoretical Background
3.1. Understanding Urban ICT and Urban Computing

Information and communication technology (ICT) theory has been applied to almost all human endeavors and thus spheres of society. In the sphere of urban planning and development, the concept of ICT refers to a set of urban technologies, infrastructures, applications, services, and computational analytics capabilities employed for sensing, collecting, analyzing, synthesizing, manipulating, mining, modelling, managing, networking, exchanging, and sharing urban data for the purpose of monitoring, understanding, guiding, and planning modern cities to achieve particular goals. This involves a variety of ways of remedying a wide range of problems affecting the long–term health and efficiency of the city as well as the quality of everyday life of its citizens. At the technical level, urban ICT includes hardware and software infrastructure. The former entails sensors and computers (e.g. RFID, GPS, infrared sensors, smart sensors, wearable computers, terminals, and smart mobile phones), Internet infrastructure, wireless communication networks, telecommunication systems, cloud computing

platforms, and middleware infrastructure. The latter includes all kind of software applications operating and running in these hardware systems, including big data analytics techniques (e.g. data mining, machine learning, and natural language processing), database integration methods, modelling/simulation methods, visualization formats, real–time operation methods, and communication and networking protocols. ICT spans over a myriad of city domains, and can be integrated in city infrastructure, architecture, networks, facilities, spatial structures, and physical objects, as well as attached to citizens and spread along the trajectories they follow during their daily activities. Urban ICT can be best spoken of based on the context of use, e.g., smart mobility and transport, smart energy, smart environment, smart healthcare, smart education, smart planning, and smart parks.

Urban computing has been used interchangeably with urban ICT; however, there is still a distinction between the two concepts. Drawing on Bibri (2015b), urban ICT theory deals with the application of ICT in and its effects on urban society, and urban computing theory is concerned with the way ICT systems are created and operate in relation to urban planning and design. Entailing a process of big and heterogeneous data collection (from diverse sources in urban spaces), integration, analysis, and synthesis (Zheng et al. 2014), urban computing has emerged as a set of computational tools and processes to tackle the pressing issues engendered by the rapid urbanization and the challenges of sustainability facing cities by using various kinds of urban data, e.g., human mobility data, spatiotemporal data, traffic flow data, environmental data, energy data, and transport data. It is an interdisciplinary field where computing as a range of scientific and technological areas (e.g. computer and information science, information technology and systems, computer and software engineering, and wireless and sensor networks) and city–related or urban planning fields (e.g. environmental planning, transportation planning, land use planning, landscape architecture, civil engineering, urban design, ecology, economy, and sociology) converge in the context of urban spaces. It deals with the study, design, development, and implementation of computing technology in urban areas and systems. Specifically, it involves designing and constructing urban–oriented systems and applications to serve multiple urban goals and make them behave intelligently as to decision support; representing, modelling, processing, and managing various kinds of urban data; discovering and collecting information relevant to various purposes, and so forth. Urban computing employs many of the technological paradigms introduced by the new wave of computing, i.e., an era when, in the urban context, computer technology disappears into urban environments and recedes into the background of urban life, to draw on Weiser (1991). This involves the use of ubiquitous sensing, information processing (data analytics models and management), wireless networks, and service provisioning, all functioning unobtrusively and invisibly in the background of urban life to help improve urban operational functioning, enhance urban life quality, facilitate daily urban activities, understand the nature of urban phenomena, and plan or foresee the future of cities.

3.2. The Prevalent ICT Visions of the New Wave of Computing
3.2.1. Defining Characteristics

Implying a slightly different focus, UbiComp, AmI, the IoT, and SenComp depict ICT visions of pervasive computing—i.e., an era when computer 'technology recedes into the background of our lives' (Weiser 1991). Since 1991, Mark Weiser foresaw this technological development and labeled it 'the computer for the 21st century'. These ICT visions are characterized by a future loaded with interconnected, interacting, deciding, and acting—and thus smart—everyday objects and devices as augmented with miniature sensors and actuators, tiny microelectronic processors, and wireless communication capabilities, as well as by a whole range of the fascinating opportunities this future will bring that are created by the (extensive) incorporation of computer technology into the very fabric of the city and thus citizens' everyday lives, to draw on Bibri (2015b). The vision of the future of technology—reflected in a variety of terms (e.g. invisible computing, calm computing, proactive computing, wearable computing, and Things that Think, in addition to UbiComp, AmI, the IoT, and SenComp)—is associated with far–reaching, long–term societal and thus urban implications.

The concept of AmI describes an era when ubiquitous computing, communication, and intelligent user interfaces will function in such an unobtrusive way and converge in such a seamless way as to render technology completely calm and wholly invisible, with each citizen enjoying an experience of interaction with the environment that anticipates and intelligently responds to their needs and desires. ISTAG (2003, p. 8), the European Union's Information Society Technologies Advisory Group,

describes AmI as a vision where people will 'be surrounded by intelligent interfaces supported by computing and networking technology that is embedded in everyday objects... AmI implies a seamless environment of computing, advanced networking technology and specific interfaces. This environment should be aware of the specific characteristics of human presence and personalities, adapt to the needs of users, be capable of responding intelligently to spoken or gestured indications of desire, ...AmI should also be unobtrusive, often invisible: everywhere and yet in our consciousness—nowhere unless we need it.' AmI has taken on many other definitions in the literature. (See Bibri (2015b) for a comprehensive overview). The concept of 'UbiComp' denotes that computer technology will permeate everyday human environment, and function invisibly and unobtrusively in the background, and make everyday objects smart by enabling them to communicate with each other, interact with people and their objects, and explore their environment, thereby helping people to carry out their daily activities or cope with their tasks in more intuitive ways and whenever and wherever needed, to draw on Weiser (1991). It is alluded to as a 'computing environment in which each person is continually interacting with hundreds of nearby wirelessly interconnected computer…essentially invisible to the user.' (Weiser 1993, p. 75) The concept of the IoT (e.g. Huang and Li 2010; Uckelmann, Harrison and Michahelles 2011) refers to a computationally augmented everyday environment where the physical world (everyday objects) and the information world (information processing) are integrated within the ever–growing Internet infrastructure via a wide range of active and smart data–sensing devices, including RFID, NFC, GPS, infrared sensors, accelerometers, and laser scanners. Bibri (2015b, p. 33) defines the IoT as 'the interconnection of uniquely identifiable embedded devices, physical and virtual objects, and smart objects [connected to humans, embedded in their environments, and spread along the trajectories they follow] using Internet Protocol version 6 (IPv6) [a new addressing infrastructure of the Internet with an unlimited capacity], embedded systems, intelligent entities, and communication and sensing–actuation capabilities'. The IoT as an intriguing construct that is evolving into more and more sophisticated network of (sensor) devices and physical objects is estimated to involve all kinds of everyday objects, including people, roads, railways, bridges, streets, buildings, water systems, electrical networks, vehicles, appliances, goods, machines, animals, plants, soil, and air. In short, the connectivity achieved by the IoT involves people, machines, tools, and places. The aim of using the IoT is to achieve different intelligent functions from conducting information exchange and communication, including learning about things, identifying things, tracking and tracing things, connecting with things, searching for things, monitoring things, controlling things, evaluating things, managing things, operating things, repairing things, and planning things (Bibri 2015b). SenComp entails using sensing devices to observe and monitor and computing devices to perceive (recognize and interpret) the physical environment and react to it. It is the idea that applications can be made more perceptive and responsive by becoming aware of and reacting to their surroundings. This also applies to several application areas of AmI as smart environment (e.g. Bibri 2015a; Bosse et al. 2007). Indeed, AmI and SenComp have been used interchangeably in the urban context (e.g. Crang and Graham 2007; Shepard 2011).

The rationale behind opting for and hence defining the above concepts is that the ICT visions they pertain to are more prevalent than those associated with their counterparts. This is manifested in the emergence and dominance of ambient, sentient, ubiquitous, and Internet–of–everything cities (e.g. Böhlen and Frei 2009; Crang and Graham 2007; Shepard 2011; Thrift 2014; Shin 2009; Lee et al. 2008; Kyriazis et al. 2014). Enabling different kinds of computationally augmented urban environments in emerging cities and seeking to connect citizens with such environments and each other, the technologies underlying UbiComp, AmI, SenComp, and the IoT will generate all kinds of smart applications and services, such as smart living and working, smart healthcare, smart education, smart energy, smart climate, smart buildings, smart transport, smart mobility, smart accessibility, smart safety, and smart planning and design (see Bibri and Krogstie 2016c for a detailed overview). These can be integrated with the typologies, design concepts, and urban management systems of existing sustainable urban forms to improve their contribution to sustainability (Bibri and Krogstie 2016b).

3.2.2. Overlays in Conceptions

While all of the above concepts tend to resemble each other, they entail a slight difference in terms of focus, orientation, or the nature and scope of the applications they cover. The concept of AmI is similar to UbiComp in the sense of intelligence being everywhere (e.g. Poslad 2009; Bibri 2015a). AmI is seen as the direct extension of UbiComp, as it adds the feature of adaptiveness and

responsiveness to the user's needs and behaviors (e.g. Riva et al. 2003; ISTAG 2003). Compared to UbiComp, AmI is concerned more with the use of the technology by people than the technology itself, i.e. AmI centers on users in their environment and is user–pull oriented whereas UbiComp focuses on next generation computing and is technology–push oriented. As to the IoT compared to AmI, the focus in 'the IoT is on the use of the existing Internet structures to link devices and objects, a technological feature that is not a prerequisite in AmI' (Bibri 2015b, p. 32). However, the IoT entails, like AmI, sensors and actuators, smart things, and wireless technologies. One implication of this is that the IoT applications can configure themselves in reaction to, or when exposed to, new environments, an intelligent behavior that can autonomously be triggered to cope with potentially unforeseen situations (Vongsingthong and Smanchat 2014). With embedded smart sensors, smart things can 'process information, self–configure, self–maintain, self–repair, make independent decisions, or even play an active role in their own disposal' (Vermesan and Friess 2013). Objects are said to have AmI capabilities, when they interact with the environment and act autonomously (e.g. Bibri 2015a). The slightly different focus implied by the concept of SenComp in relation to AmI lies in that it looks at the environment as the interface, and this environment could represent spatial scales or geographical locations. In this context, a common use of sensing and computing devices is to build and maintain a world model which allows various context–aware applications and environments to be constructed and operate intelligently. Notwithstanding there are demarcation lines between Ubicomp, AmI, the IoT, SenComp, and other related fields, 'efforts emanating from all of these fields modulate urban life and their effects overlap and reinforce one another' (Böhlen and Frei 2009, p. 1).

3.3. Smart Cities

Underlying the term 'smart city' is the idea that various urban systems and domains become interconnected through ICT for their better efficiency, management, and planning. Specifically, a smart city denotes an urban innovation that aims at, by exploiting the potential of ICT, harnessing physical and social infrastructures as well as natural and knowledge resources for environmental and economic regeneration and enhanced public and social services. Smart city has many faces, which tend to vary based on how and in what ways ICT is applied, the extensiveness of its use, and the degree of its pervasiveness, including virtual cities, networked cities, intelligent cities, knowledge cities, hybrid cities, ubiquitous cities, ambient cities, sentient cities, Internet–of–everything cities, and so on. But common to all these urban approaches is the idea that ICT is, and will be for many years to come, central to the operational functioning and planning of the city. There is no canonical or universally agreed definition of smart city. It is a difficult concept to pin down, and is often context dependent—i.e., diverse smart city initiatives are based on projects pertaining to the development of ICT. It is also based on the area of focus (see Al Nuaimi et al. 2015). However, identifying an operational definition for the scope of this study is useful. In this regard, three definitions or descriptions can be identified. A description of smart city provided by Caragliu, Del Bo and Nijkamp (2009, p. 6) is based on a model that has been used as a classification system—developed through six distinct dimensions, namely smart mobility, smart environment, smart living, smart people, smart economy, and smart governance—against which smart cities can be gauged or evaluated in terms of their smart development. Here, the concept of smart city can be seen as an urban development strategy to highlight the growing role of ICT infrastructure in catalyzing and improving some dimensions of urban sustainability. Other definitions of smart city emphasize the pervasiveness of ICT, an aspect which characterizes the prevalent ICT visions of the new wave of computing, as well as the integration of ICT with urban design and planning. In this respect, Townsend (2013, p. 15) defines a smart city as an urban environment where ICT 'is combined with infrastructure, architecture, everyday objects, and even our own bodies to address social, economic and environmental problems.' Piro et al. (2014, p. 169) describe it 'as an urban environment which, supported by pervasive ICT systems, is able to offer advanced and innovative services to citizens in order to improve the overall quality of their life.' For the purpose of this study, the identified definitions can be adopted to complement each other considering their integrative and synergic nature in the ambit of smart sustainable urban development. A combination of these definitions is, in fact, of high relevance given the interdisciplinary nature of the topic on focus. Accordingly, an inductively crafted definition of smart city can be developed: a smart city can be conceived of as an effective integration of technological, built, infrastructural, operational, architectural, physical, ecological, and human systems in the built environment across several spatial scales with the aim to employ ICT as constellations of instruments and smart solutions to promote sustainable development and thereby deliver a prosperous future for citizens. A smart city

attempts to amalgamate advanced digital technologies and urban planning approaches to find innovative solutions that contribute to improving livability and enhancing sustainability (Toppeta 2010). Indeed, the true smartness is one that is driven by astute strategies for disseminating ICT innovations and mainstreaming their adoption to support the long–term goals of urban sustainability. Smart initiatives can be used to promote environmental sustainability (Kramers et al. 2014).

3.4. Sustainable Cities

Unquestionably, sustainable development has inspired and motivated many urban scholars and practitioners into a quest for the immense possibilities enabled by the development of sustainable cities—i.e., the contribution that such cities can make to lower energy use and lessen pollution and waste levels as well as to enhance human life quality. In the literature (e.g. Bibri and Krogstie 2016a; Kramers et al. 2014; Jabareen 2006; Wheeler and Timothy 2010; Rapoport and Vernay 2011; Williams 2009), many definitions are found of what a sustainable city should be or look like. Based on this literature, sustainable cities can be understood as a set of diverse approaches to applying the knowledge of urban sustainability and related technology to the planning and design of the built environment, i.e., existing and new cities. Bibri and Krogstie (2016a, p. 10) describe a sustainable city 'as an urban environment designed with the primary aim of contributing to improved environmental quality and social wellbeing over the long run, which can be attained through adopting sustainable urban development strategies to foster advancement and innovation in urban infrastructure, urban management, ecosystem service provision, and public service delivery, while continuously improving efficiency gains.' This entails working strategically towards mitigating the environmental impacts deriving from the intensive consumption of energy, while promoting social equity, safety, and stability. In more detail, sustainable cities strive to maximize efficiency of energy and material resources, create a zero–waste system, support renewable energy production and consumption, promote carbon–neutrality and reduce pollution, decrease transport needs and encourage walking and cycling, provide efficient and public transportation, preserve ecosystems, emphasize design scalability and spatial proximity, and promote livability and sustainable community.

3.5. Smart Sustainable Cities

Smart sustainable city is a new techno–urban phenomenon. So, the term only became widespread, entered the public mainstream, during the mid–2010s (e.g. Höjer and Wangel 2015; Al–Nasrawi, Adams and El–Zaart 2015; Rivera, Eriksson and Wangel 2015; ITU 2014) as a result of several intertwined social, urban, and technological shifts. The interlinked development of sustainability awareness, urban growth, and technological development have begun to converge under what is labelled 'smart sustainable cities' (Höjer and Wangel 2015). The concept has emerged on the basis of five different developments, namely sustainable cities, smart cities, ICT, sustainable urban development, sustainability and environmental issues, and urbanization and urban growth (Höjer and Wangel 2015). The term 'smart sustainable city', although not always explicitly discussed, is used to denote a city that is supported by a pervasive presence and massive use of advanced ICT, which, in connection with various urban domains and how these intricately interrelate and inform one another, enables cities to become more sustainable and to provide citizens with a better quality of life. In more detail, it can be described as a social fabric made of a complex set of networks of relations between various synergistic clusters of entities that in taking a holistic and systemic approach, converge on using and applying smart technologies that enable to continuously create, employ, and disseminate solutions that help provide a fertile environment that is conducive to improving the contribution to the goals of sustainable development. Here, ICT can be directed towards and effectively used for collecting, analyzing, and synthesizing data on every urban domain, involving forms, infrastructures, systems, networks, facilities, and individuals, and where this information can be utilized—to the extent the citizens wish and no more—as well as to fashion or develop powerful new forms of urban simulation models and hence build and gain strong predictive capabilities for strategic decision–making to advance urban sustainability. The combination of smart cities and sustainable cities, of which many diverse definitions are available, has been less explored as well as conceptually difficult to delineate due to the multiplicity and diversity of the existing definitions. ITU (2014) provides a comprehensive definition based on analyzing around 120 definitions, 'a smart sustainable city is an innovative city that uses…ICTs and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and

future generations with respect to economic, social, and environmental aspects.' Another definition put forth by Höjer and Wangel (2015, p. 10), deductively crafted and based on the concept of sustainable development, states that 'a smart sustainable city is a city that meets the needs of its present inhabitants without compromising the ability for other people or future generations to meet their needs, and thus, does not exceed local or planetary environmental limitations, and where this is supported by ICT.' This entails unlocking and exploiting the potential of ICT as a critical driver for environmental, social, and economic development and innovation, where ICT is conceptualized as an enabling and constitutive technology, thereby its transformational effects as to addressing environmental and socio–economic challenges and thus providing a better quality of life for citizens.

3.6. Urban Sustainability and Sustainable Urban Development

The concepts of sustainability and sustainable development have been applied to urban planning and design since the early 1990s (e.g. Wheeler and Beatley 2010), thereby the emergence of the notions of urban sustainability and sustainable urban development. Urban sustainability denotes a desired state in which the urban society strives for promoting environmental integration, economic development, and social equity within sustainable urban forms as long–term goals through the strategic process of sustainable urban development as a desired trajectory. Thereby, it seeks to create healthy, livable, and prosperous human environments with minimal demand on resources and minimal impact on the environment (toxic waste, air and water pollution, hazardous chemicals, etc.), to draw on Bibri (2013). This entails fostering linkages between technological innovation, scientific and social research, institutionalized practices, and policy design and planning in relevance to urban sustainability. Urban sustainability tends to be cast in terms of four dimensions: the form, the environment, the economy, and equity, which should all—given their interdependence, synergy, and equal importance—be enhanced over the long run in a sustainable urban society. Accordingly, a city should retain a balance between physical, environmental, economic, and social concerns and goals. To achieve this long–term goal requires an urban development strategy that facilitates and contributes to the design, implementation, evaluation, and enhancement of urban systems and other practical interventions that promote urban sustainability in terms of replenishing resources, lowering energy use, lessening pollution and waste levels, as well as improving social justice, stability, and safety. This is what constitutes sustainable urban development.This notion means developing (and/or redeveloping) the city in ways that provide livable and healthy human environments with enhanced quality of life and wellbeing in conjunction with decreased demand on resources and environmental impacts, to iterate, thereby steering clear of leaving a burden on the future generations due to environmental degradation or ecological deprivation. Rechardson (1989, p.14) defines sustainable urban development as 'a process of change in the built environment which foster economic development while conserving resources and promoting the health of the individual, the community, and the ecosystem.' However, conflicts among the goals of sustainable urban development to achieve the long–term goals of urban sustainability are very challenging to deal with and overcome. This has indeed been, and continues to be, one of the toughest challenges facing urban planners and scholars as to decision making in the ambit of sustainable cities. Despite sustainable development seeking to provide an enticing, holistic approach into evading the conflicts among its goals, these conflicts 'cannot be shaken off so easily', as they 'go to the historic core of planning and are a leitmotif in the contemporary battles in our cities', rather than being 'merely conceptual, among the abstract notions of ecological, economic, and political logic' (Campbell 1996, p. 296). Even though these goals co–exist uneasily in the city, sustainable urban development as a long–range objective for achieving the aim of urban sustainability is worthy for urban planners, as they need a strategic process to reach a sustainable city. Planners will in the upcoming years 'confront deep–seated conflicts among economic, social, and environmental interests that cannot be wished away through admittedly appealing images of a community in harmony with nature. Nevertheless, one can diffuse the conflict, and find ways to avert its more destructive fall–out.' (Campbell 1996, p. 9) In other words, sustainable urban development advocates can and ought to seek ways to make the most of all three value–sets at once. This is in contrast to keep on playing them off against one another. With that in mind, the synergistic and substantive effects of sustainable development on forms of urban organization, planning, and development require cooperative effort, collaborative work, and concerted action from diverse urban stakeholders in order to take a holistic view of the pressing issues and complex challenges facing the contemporary city.

3.7. Understanding Discourse in the Urban Context

Our understanding of virtually all aspects of social life is grounded in discourses: this is the way we make sense of, or ascribe meaning to, the world around us. Indeed, discourses are at the core of social constructionism, which develops understandings about the world that constitute the basis for shared assumptions about reality. Social reality 'is produced and made real, i.e., social and political actions are engineered and become meaningful, through discourses, and social interactions with their various forms of social processes cannot be utterly comprehended without reference to the discourses that give them meaning and form' (Bibri 2015b, p. 39) in the first place. In other words, the constitution of social life occurs through discursive practices (text production and consumption processes). This entails that discourses produce knowledge through language and social construction and thereby entail how this knowledge is institutionalized and conventionalized, thereby shaping social practices and setting new ones into play. On this note, Foucault (1972) asserts that all social practices have a discursive aspect because they entail meanings that shape and influence our actions. It follows that sociocultural change and reproduction take place through discursive practices (e.g. Foucault 1972; Phillips & Jørgensen 2002). Underlying the term 'discourse', in this context, is the idea that language as a form of discursive practice is structured according to a system of statements (e.g. what can be said about ICT of the new wave of computing for urban sustainability or smart sustainable cities) used by people (e.g. urban planners, ICT experts, computer scientists, researchers, policymakers, and institutions) as a particular way of understanding, talking about, and producing a particular kind of knowledge about the urban world (e,g, the physical, spatial, environmental, economic, and social dimensions of the city), as well as taking part in different domains of urban life (e.g. urban planning and design, urban research, urban sustainability, applied urban science, and big data city analytics), to draw on Bibri (2015b). Foucault (1972) defines discourses as practices which form the object that discourses talk about. In other words, discourses constitute the conditions of possibility for socially anchored and institutionalized practices. In the context of this study, the object takes the form of a coherent set of ideas, concepts, terminologies, claims, assumptions, categorizations, visions, and prospects pertaining to ICT of the new wave of computing for urban sustainability that are constructed, reconstructed, transformed, and challenged in smart sustainable urban planning and development practices, and that through which meaning is given to the smart sustainable city as an amalgam of physical, spatial, infrastructural, operational, functional, social, and ecological systems and processes supported with ICT, which forms the new urban reality.

4. Analytical and Philosophical Analysis: the Social Shaping Dimensions of Smart Sustainable Cities

4.1. On the Origin and Nature of Smart Sustainable Cities

The debate focusing on the untapped potential of ICT for catalyzing and boosting sustainable development towards achieving the long–term goals of sustainability (e.g. Alakeson et al. 2003; Fuchs 2005; Madden Weißbrod 2008; Bibri 2013) relates to the academic discourse of ICT for sustainability. This discourse has given rise to other discourses such as ICT for urban sustainability (e.g. van den Berg and van Winden 2000; Bibri 2013) and ICT for environmental sustainability (e.g. Fuchs 2005). The discourse of ICT of the new wave of computing for urban sustainability has emerged and gained popularity after the prevalent ICT visions of pervasive computing (namely UbiComp, AmI, the IoT, and SenComp) have become deployable and achievable computing paradigms. Also, the possibility for amalgamating these computing paradigms through the underlying enabling technologies (sensor networks, data processing platforms, and wireless networks) in relation to a number of urban application domains (e.g. Bibri and Krogstie 2016c) has contributed significantly to the materialization and prevalence of this discourse. These discursive factors have subsequently led to the emergence of smart sustainable cities as techno–urban transformations. Phillips and Jørgensen (2002, p. 7) state, 'by combining elements from different discourses…concrete language use can change the individual discourses and thereby, also, the social and cultural world'. However, all these discourses metonymically represent the discourse of sustainable information society, a meta–discourse which regulates the techno–urban discourse of smart sustainable cities. Sustainable information society denotes 'a society in which new…ICT…and knowledge are used in order to advance a good–life for all individuals of current and future generations. This idea is conceived in a multidimensional way,

identifying ecological, technological, economic, political, and cultural aspects and problems' (Fuchs 2005, p. 219). And smart sustainable city refers to 'an innovative city that uses…ICT and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, and environmental aspects.' (ITU 2014).

Advances in S&T (predominantly computing and ICT) inevitably bring with them wide–ranging common discourses and visions on how cities as forms for human settlements and complex systems will evolve as well as on the immense opportunities to benefit from and the potential risks to face. The techno–urban discourse of smart sustainable cities expresses a vision of city with healthy, livable, and prosperous human environments as well as minimal demand on resources and minimal environment impacts, all enabled by advanced computing and ICT as a form of S&T. In this vision, ICT solutions hold great potential to tackle and solve environmental and socioeconomic problems, or to address the challenge of sustainability. And in this discourse, there is a construction of 'the city' as a relevant techno–urban category and as something desirable and often equal with the objects, yet not the scope, of city governments. Further, similar discourses pertaining to other spheres of society have been common with the advent of technological innovations and breakthroughs. They have made claims and promises about different kinds of social transformations on the basis of the innovations and breakthroughs enabled by computing and ICT over the last few decades. All such discourses can be stimulating and compelling when new and strongly disruptive technologies (e.g. UbiComp, the IoT, AmI, SenComp) are emerging and pervading into society. Unlike other techno–urban discourses (e.g. smart cities), which have failed to deliver what they claim or live up to their expectations due to the underlying technologically deterministic view, smart sustainable cities already place a strong focus on urban dynamics around the new features enabled by ICT of the new wave of computing and their potential adoption for advancing sustainability, rather than solely emphasizing these new features. The rationale behind this argument is that smart sustainable cities are taken to mean or assumed to be ecologically sustainable based on established theoretical foundations of sustainable urban planning, and ICT of the new wave of computing is seen more as a constitutive and integrative technology whose transformational effects can be unlocked and leveraged in the advancement of urban sustainability. As concluded by Kramers et al. (2014), there is a weak connection between smart cities and environmental sustainability, as these cities have little to do with environmental solutions or concerns, and are intended to promote urban image and attractiveness and thus attract investment, businesses, and citizens; hence, it is suggested to use the concept of smart sustainable cities as a way of linking smart initiatives with environmental sustainability. There is tremendous untapped potential for harnessing the creative and disruptive power of ICT of the new wave computing to transform the way the sustainable cities function and ultimately the way citizens improve their sustainable living. With the above reasoning in mind, the techno–urban discourse of smart sustainable cities tend to reflect realistic assumptions about the evolution of sustainable urban practices, enabled by the applications and extension of complexity sciences, which ICT of the new wave of computing is founded on, as well as about the complexity and scalability of the frameworks proposed for advancing urban sustainability. In this sense, the intention is not to mimic and enhance existing urban functions and practices, but rather let the disruptive nature of technological innovations and breakthroughs dictate. It may well be more beneficial to search for the emergence of new sustainable urban practices around ICT of the new wave of computing and its wider use in the urban domain. In this respect, new sustainable urban practices can develop around advanced ICT (e.g. big data in city analytics), and it can further be adapted and integrated into such practices, thereby enhancing its use in a way that fits into a wider strategy that makes it more meaningful and strategically focused.

Referring to smart sustainable cities as a discourse is predicated on the assumption that it is a techno–urban phenomenon for which there is no clear, definite, and widely acknowledged definition, in addition to the fact that urban scholars and practitioners are writing about it. And in doing so, they are engaging in debates about smart forms of sustainable urban development. The discussions resulting in or forming this new discourse produce and make real the new urban reality of smart sustainable cities and thus develop jointly constructed understandings, thereby the social construction of the related techno–urban category (see Section 4.6. for further detail). Indeed, the techno–urban discourse of smart sustainable cities is becoming powerful and established (e.g. Höjer and Wangel 2015; Al–Nasrawi, Adams and El–Zaart 2015; Rivera, Eriksson and Wangel 2015; Kramers et al. 2014; Bibri

and Krogstie 2016b, c), as contemporary urban scholars and practitioners relate to it in a structured way in many contexts of their practices—socially anchored and institutionalized actions.

Conceptualized as an interplay between scientific innovation, technological innovation, environmental innovation, urban design and planning innovation, institutional innovation, and policy innovation, smart sustainable cities represent and involve inherently complex socio–technical systems of all sorts of innovation systems. Such systems, which focus on the creation, diffusion, and utilization of knowledge and technology, are of various types (variants of innovation models), including national, regional, sectoral, technological, and Triple Helix of university–industry–government relations (e.g. Edquist 1997, 2005, 2011; Carlsson et al. 2002; Etzkowitz and Leydesdorff 2000). As a set of techno–urban innovation systems, smart sustainable cities thus result from a dynamic network of relationships among universities, research institutes, governmental agencies, policy makers, industry consortia, and business communities involved in various innovation systems. In the literature, innovation models have been approached from different perspectives (e.g. Marinova and Phillimore 2003; Lindell 2012). For example, Marinova and Phillimore (2003) provide a historical examination of innovation models which are used to explain innovation as a process generating new products and methods (e.g. ICT solutions and approaches for urban sustainability) in terms of the activities and stakeholders involved (e.g. urban activities and actors). This study adheres to the socio–technical system approach to innovation system, which entails the components needed to fulfill a certain societal function (Bijker 1995; Geels 2004), e.g. advancing urban sustainability. The typically complex, diverse sets of socio–technical systems underlying smart sustainable cities entail different elements of innovation in the form of smartness and development across many urban domains (transport, environment, energy, healthcare, education, planning, etc.) for the purpose of advancing sustainability and integrating its dimensions. Of all introduced innovation models, the technological innovation system is of prime focus here considering the scope of this study. The technological innovation system has developed into a widely accepted and applied theoretical framework and analytical tool. it denotes 'socio–technical systems focused on the development, diffusion, and use of particular technologies' (Bergek et al. 2008, p. 408), or dynamic networks of actors interacting within a specific industrial sector (e.g. transport, healthcare, energy) under a particular institutional set–up in the production, diffusion, and utilization of new technologies (e.g. Carlsson and Stankiewicz 1991; Carlsson et al. 2002), e.g. UbiComp, AmI, the IoT, and SenComp for urban sustainability. As proposed in the literature on socio–technical systems (Geels 2004), technologies are seen as systems of socio–technical elements interacting with each other (e.g. for promoting and applying new technologies to urban sustainability), an approach which provides insights into understanding the development of new technologies. In all, the technological innovation system approach can explain why and how new technologies for urban sustainability have been developed, diffused, and utilized in smart sustainable cities within technologically and ecologically advanced nations. It is part of a wider theoretical approach to innovation system whose core idea, which explains the rate, nature, and direction of technological change, is that the determining factors thereof are not only to be found in industrial firms, firms of expertise, industry consortia, and research institutes and universities, but also in the wider societal structures where such firms, consortia, and institutes are embedded (see Section 4.10. for further discussion).

4.2. Cultural Frames and Changes Surrounding Smart Sustainable Cities

There is a dialectic relationship between discourses and cultural frames in that discourses are shaped by and also influence cultural frames. In more detail, cultural frames exist within and through the coexisting discourses circulating in society, and are in these discourses reconstructed, transformed, and challenged as well as shape how these discourses evolve new forms, as both change through social practices. Advanced by Fisher (1997, p. 5), the concept of cultural frames refers to 'socio–culturally and cognitively generated patterns which help people to understand their world by shaping other forms of deep structural discourse'. Accordingly, smart sustainable cities are the product of a socio–culturally–conditioned framework in terms of how the associated urban practices have evolved through sociopolitical institutions as well as social processes which create and maintain knowledge pertaining to urban development (e.g. establishing an intellectual connection between ICT of the new wave of computing, sustainability, and urban planning. It is in social processes that the ways in which we understand the world are produced and perpetuated (e.g. Burr 1995; Gergen 1985). Social processes are forms of social interaction in which common truths, values, assumptions, claims, and

legitimacies are constructed (e.g. Bibri 2015b). Further, smart sustainable cities have in large part been brought to existence through strategic societal actors and their cultural frames that are attuned to the values of, and conventionalized by, technologically and ecologically advanced societies in relation to scientific innovation and technological development and their role in bringing about social transformations (e,g, sustainable urban change). Inextricably linked to, if not equated with, social constructs, which form the basis for shared assumptions about reality, cultural frames, which constitute shared forms of understanding the world, pertain to the meaning or connotation placed on the objects and their associated subjects with different material interests pertaining to smart sustainable cities that are constituted discursively by those societies and adopted by their constituents with respect to how they view or deal with the objects and subjects in question. Important to note is that social constructs or cultural frames may or may not represent a reality shared by those outside ecologically and technologically advanced societies. Yet, they have significant and often unrealized effect on people's perceptions of reality. They are, drawing on Moscovici (1984), 'prescriptive in the sense that they represent a force, a combination of structures and traditions, which shapes the way people think and what they ought to think' (Bibri 2015b, p. 64). As an example of cultural frames relating to ICT in the information society, ISTAG (2006, p. ii) states, 'ICT does not just enable us to *do* new things; it *shapes* how we do them. It transforms, enriches and becomes an integral part of almost everything we do. …ICT becomes more deeply embedded into the fabric of…society… These constitutive effects amount to a paradigm shift in how our…society functions.' ICT research plays a key role in unlocking the transformational effects of ICT for societal sustainability (ISTAG 2006). ISTAG (2003, p. 8) adds in relation to AmI as a key component of ICT of the new wave of computing, 'we should not underplay the radical social transformations that are likely to result from the implementation of the AmI vision.' Therefore, the cultural frames linked to the role of ICT of the new wave of computing in societal development have shaped the structural discourse of smart sustainable cities as an instance of sustainable urban development. Indeed, smart sustainable cities typically rely on the prevalent ICT visions of pervasive computing or ICT of the new wave of computing—a combination of various forms of pervasive computing (e.g. Bibri and Krogstie 2016c). As far as the discursive constructions of ICT of the new wave of computing for urban sustainability shaped by the prevailing cultural frames in the context of smart sustainable cities are concerned, they are covered in the next section. However, a key argument to underscore is that alternative discursive constructions could have been made had advanced societies chosen so. This implies that such discursive constructions will be formulated and thus new discourses on cities will be shaped in light of advanced conceptions about the societal changes yet to come. Fundamentally, discursive positions and constructions become recurrent and start sedimenting over time, respectively, as new alternative views and changes to arguments emerge and the established discursive positions and constructions get questioned and challenged. This occurs as people act upon discovered knowledge over and over and in doing so, transform discourses via social practice and social interaction.

The techno–urban discourse of smart sustainable cities is not shaped solely by the prevalent cultural frames, but also by recent cultural changes associated with advances in sustainability science and innovations in ICT. In fact, such changes have significantly affected the common cultural frames surrounding sustainable cities and smart cities, which have in turn given rise to a holistic approach into sustainable urban development as a deep structural discourse. In this regard, challenges have come from the macro level through cultural shifts relating to the increasing incorporation of environmental and socioeconomic concerns into regulatory incentives and policy frameworks as well as into norms and behavioral patterns in urban development. Adding to this is the growing societal realization that cities have become more complex through the very technologies being used to understand, analyze, and plan them in terms of their contribution to sustainability, thereby the need for the integration of complexity sciences in their understanding, which ICT of the new wave of computing is founded on (see, e.g., Batty et al. 2012; Bibri and Krogstie 2016b). Drawing on Smith (2003), drastic shifts to smart sustainable systems entail concomitantly drastic changes to the socio–technical landscape (including politics, policy, institutions, and social values), which involves such trends as increased sustainability awareness, climate change policy, and shifts to innovative cities. In all, smart sustainable cities as a techno–urban innovation entail parallel cultural, social, and political shifts. Hence, it is of high relevance to recognize the interplay between smart sustainable cities and other macro scales and the links to urban politics and urban processes of regulation (e.g. environment, technology, and innovation policy in support of cities).

4.3. Discursive Constructions of ICT of the New Wave of Computing for Urban Sustainability: Social and Scientific Grounds

Discursive constructions entail the ways in which the discursive objects of ICT of the new wave of computing are constructed. Here such constructions are situated within the discourse of smart sustainable cities. As ICT has become more sophisticated and deeply embedded into the very fabric of the contemporary city, it has provided many new opportunities to make sustainable urban development work by drastically transforming the way the city functions in terms of sustainability and efficiency (e.g. Batty et al. 2012; Bibri and Krogstie 2016a, b). And the new digital transition fueled by ICT of the new wave of computing and its constitutive nature, on which cities are increasingly engaging, is projected to bring about further transformational effects. It has been widely acknowledged that technological innovations embody a transforming power in that they alter how cities function and reshape or create new realities. Viewing ICT as a constitutive and integrative technology represents a widening and deepening of UbiComp–, AmI–, SenComp–, and the IoT–type approaches at the level of urban applications, to draw on Bibri (2015a). These new digital technologies and their amalgamation are postulated to transform the role of ICT in the city and ultimately the way citizens live in it. This involves capturing further and invigorating the application demand for the urban sustainability solutions that emerging ICT can offer. The constitutive nature of ICT of the new wave of computing amounts to a paradigmatic change in the way the city functions, whether be it sustainable or manifestly planning to become so. The convergence of new ICT will shape future cities in fundamental—and yet unexpected—ways (e.g. Shepard 2011; Batty et al. 2012; Thrift 2014). This entails how they can be effectively monitored, analyzed, probed, assessed, and planned to improve their contribution to sustainability by relying on big data analytics and context–aware computing (Bibri and Krogstie 2016c; Al Nuaimi et al. 2015). Not only is ICT seen as a critical enabler in this regard, but also as a powerful transformative driver for sustainable sustainable cities. Indeed, without ICT, the drive to improve urban systems: physical structures and spatial organizations, urban infrastructures (e.g. transportation, communication, distributed networks, etc.), urban administration, ecosystem services, and public services, may not reach its full potential. Reaching full potential in this respect signifies new and fertile opportunities for improving urban sustainability, urban efficiency, and the quality of urban life, which ICT of the new wave of computing is extremely well placed to provide. Indeed, a number of smart technologies are being developed and applied to diverse urban activities and systems to conserve resources, lower pollution levels, reduce GHG emissions, streamline processes, and enhance living standards (Batty et al. 2012; Al Nuaimi et al. 2015; Kramers et al. 2014; Bibri and Krogstie 2016c), as well as employed to investigate and evaluate the processes of their own application, implementation, and implication on the city. The research and social practice within the area of new ICT for sustainability has a key task to fill as to urban planning and development (Rivera, Eriksson and Wangel 2015). In other words, cities entail human environments where smart solutions in line with the goals of sustainable development can be discovered, created, employed, evaluated, and improved (Höjer and Wangel 2015; Bibri and Krogstie 2016a). In a nutshell, ICT can be leveraged in the needed advancement of sustainable urban development (Shahrokni et al. 2015; Neirotti et al. 2014) and hence in addressing the challenge of urban sustainability.

Furthermore, to understand complex systems and the way they evolve, behave, and form relationships with their environment necessitates sophisticated methods and advanced models. Smart sustainable cities are complex systems, more than the sum of their parts, deal with complex challenges, and are considered as dynamically changing urban environments. It follows that the complexity sciences (e.g. information theory, non–linear dynamics, networks, pattern formation, collective behavior, emergence, adaptation and evolution, and systems theory) are integral to the understanding of, and undertaking the challenges and tracking the changing dynamics pertaining to, such cities. Besides, smart sustainable cities are inherently more complex through the very technologies being used to monitor, understand, analyze, assess, and plan them in terms of their contribution to sustainability (see, e.g., Batty et al. 2012; Bibri and Krogstie 2016b, c; Kramers et al. 2014; Al Nuaimi et al. 2015; Shahrokni et al. 2015). Hence, embedding more and more ICT in smart sustainable cities seems to be unavoidable for the sole purpose of handling their complexity in terms of the challenges they are facing and will be dealing with. The underlying premise is that ICT of the new wave of computing is founded on the application of the complexity sciences to urban systems and problems. As such, it should be instrumental not only in catalyzing and boosting the sustainable development processes of smart sustainable cities, but also in understanding, monitoring, analyzing, assessing, and planning these cities through big data

computing as well as urban intelligence functions and urban simulation models for making strategic decisions about their collective behavior and the dynamic relationship they form with the environment in the context of sustainability. These advanced technologies (e.g. Al Nuaimi et al. 2015; Batty et al. 2012; Bibri and Krogstie 2016c) constitute new conceptions of the way existing sustainable cities (e,g. Jabareen 2006; Bibri and Krogstie 2016b) can perform and be assessed with respect to their contribution to sustainability, as well as utilize the complexity sciences (Bibri and Krogstie 2016b, c) Big data analytics targets optimization and intelligent decision support for control, management, and planning purposes through the implementation of optimization strategies and decision–taking processes in relation to a wide variety of urban application domains, such as transport, environment, energy, land use, health, and education (Bibri and Krogstie 2016c). Developed through advanced ICT, urban intelligence functions, which are intended for decision support, are associated with the process of fashioning new forms of, and exploring many different kinds of modeling approaches to, simulation models as well as optimization strategies—based on the sciences of complexity—that generate urban forms and structures that enhance sustainability, efficiency, and the quality of life (Batty et al. 2012). Developing such functions enables moreover to explore the idea of smart sustainable cities as techno–urban innovation labs, which can allow their monitoring and design in relation to the efficiency of energy systems, the improvement of transport and communication systems, the effectiveness of ecosystem and public services delivery (Batty et al. 2012; Bibri and Krogstie 2016a, c). These intelligence functions can take the form of centers for scientific research and innovation with the primary purpose of continuously improving the contribution of smart sustainable cities to sustainability thanks to the possibility for building models of real–time cities from sensor data in terms of operational functioning. Moreover, they involve urban simulation models, which need to be constructed for different urban domains and how their diverse constituents interrelate. The simulation process entails creating and analyzing digital prototypes of different physical, environmental, socioeconomic, infrastructural, spatial, operational, and functional models pertaining to smart sustainable cities to predict changes in their sustainability performance and forecast problems in the real world. This is increasingly becoming achievable due to the recent advances in and pervasiveness of sensor technologies in terms of becoming able to provide data about medium– and long–term changes in the ambit of real–time cities. The importance of urban simulation models lies in aiding urban planners and designers in understanding under what conditions and in which ways urban systems or some of their components fail to deliver at the level of sustainability and what to do about potentially predicted changes or forecasted problems, e.g. enhanced integration and coordination, reorganization, and/or division of urban systems. Likewise, big data analytics utilizes complex computational processes in analyzing urban phenomena, improving urban operational functioning, and enhancing the planning of urban systems. The evolving developments in data computation, processing, and management can be integrated and harnessed so to make smart sustainable cities evolve in the way their planners and designers can use the available technological applications, services, and capabilities to improve sustainability, efficiency, and the quality of life. All in all, the core enabling technologies and computational capabilities underlying ICT of the new wave of computing allow gathering, processing, and analyzing various kinds of urban data on several urban domains and systems across different spatial scales and over different time spans, and the outcome is important for developing urban intelligence functions for decision making and urban simulation models for gaining predictive insights. All this can serve for making strategic decisions in the ambit of smart sustainable cities in terms of addressing the complex challenge of sustainability. This implies that big data analytics should be supported by advanced intelligence functions, integrated decision support systems, and comprehensive simulation models for linking the components of smart sustainable cities to their operational functioning and planning and thus advancing their sustainability.

With the above in mind, there is an increasing recognition that ICT of the new wave of computing constitutes a promising response to the challenge of urban sustainability due to its potential to advance and maintain sustainable urban development processes. Subsequently, strengthening the role of ICT in sustainable urban development has been given more significance and supported by endeavors for unlocking its transformational potential by exploiting the disruptive and constitutive nature of new digital technologies in relation to many urban domains. ICT of the new wave of computing is expected to yield environmental gains and socioeconomic benefits in line with the vision of sustainability, owing to its 'technological superiority in terms of the novel applications, services, and products that provide advanced performance and value' (Bibri 2015b). Adding to the fact that it ushers in automation in nearly every urban domain and system. This implies that the range of applications that

utilize UbiComp, AmI, the IoT, and SenComp in connection with the urban sustainability domain is potentially huge, and significant opportunities are said to exist for these technologies, separate or combined, in relation to modernizing the urban model particularly in terms of advancing sustainability (see next section for a detailed account). It is clear that ICT of the new wave of computing provide novel solutions and sophisticated methods for addressing numerous environmental and socioeconomic challenges associated with sustainability that are facing cities.

If linked with sustainable development and thus utilized meaningfully, ICT of the new wave of computing, which epitomizes the intensive integration of diverse forms of intelligence into urban environments and citizens' everyday lives, will have positive, profound, and long–term impacts on the city—drastic sustainable urban transformation. In this regard, future scenarios are perceived to be, to a great extent, grounded in realistic assumptions about reasonable prospects (of high modern applicability) on how ICT, the city, and citizens will evolve with respect to sustainable urban living. Besides, in the discourse of information society, ICT is socially constructed as a powerful enabler and driver for social transformation (e.g. ISTAG 2006) and environmental modernization (e.g. Bibri 2015b). Specifically, 'the underlying belief of the information society discourse is that a total social transformation is envisioned or predicted and that this transformation is a positive and progressive movement.' (Bibri 2015b, p. 139) By the same token, at the core of ecological modernization as an academic and environmental discourse is an established view of the potential for technological innovations to bring about advanced solutions for environmental problems. Ecological modernization is concerned with the shifts in 'the central institutions and core practices of modern society deemed necessary to solve, avoid, or mitigate the ecological crisis' (Bibri 2015b, p. 35). One of its key dimensions is technology and the transformation of society (Huber 1985), which entails that environmental problems could be addressed through the development and application of more advanced and sophisticated technologies (Murphy 2000). In relation to sustainable urban transformation, the existing evidence (e.g. Bibri and Krogstie 2016a; Batty et al. 2012; Al Nuaimi et al. 2015; Neirotti et al. 2014; Kramers et al. 2014) lends itself to the argument that the ubiquity presence and massive use of ICT, in relation to every urban domain, makes it a salient factor for advancing urban sustainability. It follows that for the contemporary city to improve sustainability, ICT of the new wave of computing is seen as the way forward to achieve this goal.

4.4. Social Implications of the Discursive Constructions of ICT of the New Wave of Computing for Urban Sustainability: ICT Applications and Services for Smart Sustainable Cities

A social constructionist worldview posits that particular understandings of the social world leads to particular social actions, whereby some forms of actions become legitimate and others unthinkable (e.g. Burr 1995). This is in discursive terms referred to as the dialectic relationship between social knowledge (and its discourses) and social practices. In light of this worldview, certain urban actions within smart sustainable cities as a form of urban practice become legitimate from within the discourse of ICT of the new wave of computing for urban sustainability, and such actions, in turn, reproduce and support this discourse that legitimates them in the first place (see Bibri 2013). Accordingly, this discourse is reshaping the activities, actions, functions, and processes of smart sustainable cities, as well as the meanings the urban actors ascribe to their projects and undertakings. In a nutshell, as linguistic utterances, this discourse has effects on urban development by engineering and shaping social and political actions and inactions within smart sustainable cities. However, the discursive constructions of ICT of the new wave of computing for urban sustainability and their associated positions open up as well as close down opportunities for actions by constructing particular ways of seeing cities as urban realities, and positioning an array of subjects (e.g. ICT industry) within such constructions in particular ways (see Foucault 1972). Among the social implications of the discursive constructions of smart sustainable cities include physical actions being complemented by extensive use of new technologies, many urban functions being replaced by computation and automation and merged with human actions across diverse urban domains, data provided from computational and automatic urban functions enabling a world in which the implications of urban operational functioning is continuously available and thereby affecting planning as to becoming continuous due to real time update to data, and so forth.

With the above in mind, ICT of the new wave of computing is socially and discursively constructed as being a powerful catalyst, enabler, and driver for urban sustainability. This is due to the fact that ICT

has played a key role in the recent years in shaping energy production and consumption in ways that have enabled substantial energy savings across many urban domains (e.g. smart buildings, smart transport and logistics, smart city planning, and smart grid) and have reduced concomitant GHG emissions, adding to advancing urban metabolism models (e.g. GeSI 2008; Bibri 2013; Griffiths 2008; Shahrokni et al. 2015). ICT has been central to addressing many other challenges facing cities, including those pertaining to planning, transport, mobility (e.g. ISTAG 2006, 2008, 2012), demobilization, dematerialization (e.g. Kramers et al. 2014), non–spatial and spatial accessibility, equity (e.g. Batty et al. 2012), and virtual mobility (virtual teams, teleworking, virtual communities, virtual meetings, etc.) (e.g. Hilty et al. 2004, 2006). For more ICT solutions, the reader is directed to Nam and Pardo (2011). These ICT solutions have led to higher levels of citizen wellbeing and comfort as well as to the efficiency and better management of urban operational functioning. The shaping role and influence of ICT of the new wave of computing is said to grow even more with the technical maturity, enhanced computational performance, and financial affordability of new technologies and their applications and services pertaining to urban sustainability. Marking new ICT developments, UbiComp, AmI, SenComp, and the IoT technologies are projected to offer new innovation opportunities that cannot be foreseen until they reach and permeate modern cities. While ICT innovations are postulated to offer advancements that significantly impact urban systems and domains and how they intricately interrelate and evolve, the focus of ICT of the new wave of computing is claimed to revolve particularly around sustainability with regard to the how of this impact. This entails justifying future investments ICT by social needs and concerns of citizens and environmental problems affecting cities. The convergence of future ICT will bring about urban environments that are unlike what has been experienced hitherto (Batty et al. 2012), especially in relation to new approaches to sustainable urban development (e.g., Bibri and Krogstie 2016c; Al–Nasrawi, Adams and El–Zaart 2015; ITU 2014).

The prospect of smart and sustainable cities getting smarter is fast becoming the new reality (e.g. Bibri and Krogstie 2016b; Batty et al. 2012; Allwinkle and Cruickshank 2011; Shepard 2011; Kramers et al. 2014; Shahrokni et al. 2015), and this is opening up new opportunities for increasing their contribution to sustainability. This has been enabled by the recent advancements in several scientific and technological areas within computing, notably context aware computing, multi–sensor data fusion, hybrid modeling and reasoning, machine learning, cloud computing, wireless and mobile networks, and, more recently, big data analytics. Subsequently, significant opportunities now exist for UbiComp, AmI, the IoT, and SenComp in relation to modernizing the urban model in terms of different dimensions of sustainability. Indeed, the range of urban applications that utilize these new technologies in connection with sustainability is potentially huge, as these technologies—combined through what has been identified as big data and context–aware computing—usher in automation in nearly all urban domains. Efforts emanating from these technological fields modulate and influence every aspect of urban life (Böhlen and Frei 2009). Accordingly, in view of their synergy and integration in terms of their operational functioning, UbiComp and AmI application areas include healthcare and social support, public services, learning and tele–working within the networked home, social groupings and community building, social inclusion, public safety, energy efficiency, environmental monitoring, disaster management, transport and mobility, water and waste management, and large–scale deployments in relation to smart cities (e.g. ISTAG 2003, 2006; Batty et al. 2012; Böhlen and Frei 2009; Shin 2009; Lee et al. 2008; Bibri 2015b; Al Nuaimi et al. 2015; Kramers et al. 2014). Likewise, the IoT application areas encompass environmental monitoring and protection (air and water quality and atmospheric conditions), urban infrastructure monitoring and management, waste management, energy management, medical and health systems, public safety, environment and disaster, building automation, natural ecosystems, transportation, and large–scale deployments in relation to smart cities (e.g. Vongsingthong and Smanchat 2014; Dlodlo et al. 2012; Kyriazis et al. 2014; Li et al. 2011; Gubbi et al. 2013; Lu and Wang 2010; Yang, Wang and Yue 2012; Rico 2014; Vermesan and Friess 2013). Overlapping with AmI, SenComp application areas involve transportation, safety and environmental impact, traffic and street light control systems, energy conservation, waste management, measuring and surveying buildings, civil security, and social and public services (e.g. Shepard 2011; Thrift 2014). Therefore, there is a lot to achieve with the deployment and implementation of these advanced solutions offered by ICT of the new wave of computing—if its potential is well focused on urban sustainability in terms of exploiting the benefits of big data and context–aware computing in the ambit of smart sustainable cities. Context awareness and big data technologies and their applications and uses play a significant role in realizing the key

aspects of the improvement of the contribution of smart and sustainable cities to sustainability. The link between urban sustainability and big data and context–aware computing provides insights into understanding how ICT of the new wave of computing can add a whole new dimension to existing smart and sustainable cities. Indeed, the main strength of big data and context–aware computing lies in the high influence it will have on many aspects of smart sustainable cities and on their citizens' lives.

Figure 1 shows the employment of big data and context–aware computing through the core enabling technologies of ICT of the new wave of computing in smart sustainable cities of the future, which connects urban domains and systems with smart applications and services. Through pervasive sensing, computing, and networking infrastructures, big data and context–aware applications collect, store, manage, process, analyze, and model data pertaining to various urban domains and systems to generate context knowledge or discover new knowledge, respectively, to help decision–makers to improve urban performance and strategic planning in relation to resources, infrastructures, networks, facilities, and services and their interrelationships in the context of sustainability. For a detailed account of such applications and services, the reader is directed to Bibri and Krogstie (2016c).
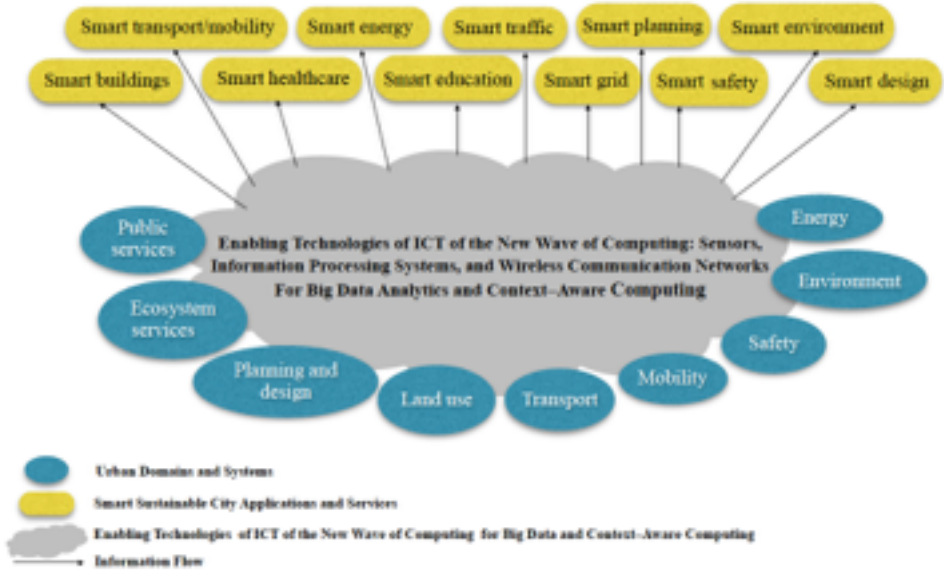

Fig. 1. Using the enabling technologies of ICT of the new wave of computing to connect urban domains and systems with smart applications and services

4.5. Discursive Hegemony of Smart Sustainable Cities

As hinted at above, the discourse of ICT of the new wave of computing for urban sustainability and the discourse of smart sustainable cities depart from and build on the same assumptions and claims. Put differently, the latter is the current defining context for the smart and innovative solutions being suggested or offered by the former, which implies that other potential urban development strategies are likely to emerge in the future. Hitherto, promoting and achieving urban sustainability with support of ICT of the new wave of computing occurs within and through smart sustainable cities, which typically rely on a combination of various forms of pervasive computing, namely UbiComp, AmI, the IoT, and SenComp (Bibri and Krogstie 2016c). With that in mind, we focus the discussion herein only on the discourse of smart sustainable cities. This discourse becoming more powerful and established as a scholarly discourse is demonstrated by the contemporary scholars and practitioners from many disciplines and professional fields, respectively, relate to it in a structured way in many contexts of smart urban planning and development practices—as documented above. In a nutshell, it is a 'hegemonic discourse' (see, e.g., Sum 2004; Hajer 1995), not least in technologically and ecologically advanced societies. The discursive hegemony of smartness over the current form of sustainable urban development, as exemplified below, is manifested in the discourse of smart sustainable cities becoming so embedded in the information society that 'appears of uttering nonsense to ask about its assumptions' (Bibri 2013). The ICT of the new wave of computing orientation of the development of

sustainable city has gained dominance in that society under that discourse, which as a separate discursive field represents a cluster of discourses that revolve around the relationship between computing, ICT, sustainable development, sustainability, and urban planning that is given meaning, form, and ultimately applied in technologically and ecologically advanced societies. This implies that this discourse has gained legitimacy as an academic discourse and thus urban planning practice—i.e., pursued though diverse urban development strategies and projects pertaining to smart sustainable cities, supported by research and innovation endeavors. In particular, the growing academic interest in this discourse is such that it has become part of mainstream debate in sustainable urban planning and sustainable city–related disciplines. This is because of the (perceived) potential of innovative ICT to catalyze and boost sustainable urban development processes and, thus, to advance urban sustainability. In addition, this discourse and its translation into hegemonic techno–urban projects and strategies and their ongoing institutionalization in urban planning and development structures and practices postulate that future visions of noteworthy advances in S&T (computing and ICT) bring with them wide–ranging visions of the future on how cities will evolve and the opportunities such future will bring as to, e.g., sustainability, efficiency, and the quality of life. The importance of techno–urban visions of the future which transpire subsequent to new scientific innovation and its technological applications lies in that such visions 'have the power not only to catch peoples' minds and imaginations, but also to inspire them into a quest for new possibilities and untapped opportunities and to challenge them to think outside common mindsets.' (Bibri 2015b, p. 3) This is of relevance as to the innovative ways that are mostly needed to address the challenge of urban sustainability and rapid urbanization (e.g. Batty et al. 2012; Bibri and Krogstie 2016a; Bifulco et al. 2016; Townsend 2013; Nam and Pardo 2011). In relation to this, like other (academic) urban discourses, the discourse of smart sustainable cities, which is constructed in the light of new conceptions about the scientific, technological, environmental, economic, institutional, social, and cultural changes over the past decade—'contains an all–embracing understanding of the problems cities are facing and is also the defining context for suggested [ICT] solutions' (Jessop 1998, p. 78) as future possibilities for the challenges and problems of urban sustainability and rapid urbanization.

4.6. Discursive–Material Dialectics, Construal, and Construction of Smart Sustainable Cities

With being a hegemonic semantic order, smart sustainable cities as techno–urban visions have been construed and constructed (see, e.g., Jessop 2004; Fairclough 2005). That is to say, they have resonated with material mechanisms and practices. Constituting techno–urban objects and their related subjects with specific material and ideal interests (discursive constructions), smart sustainable cities as techno–urban visions have a pivotal role alongside material mechanisms and practices in reproducing and/or transforming urban domination (see Sum 2006). Smart sustainable cities as representations have been discursively construed in different spatial contexts (cities within ecologically and technologically nations) and reproduced materially through institutional and organizational apparatuses and their techniques, actors, and practices (see Jessop 2004). This material reproduction entails the translation of the underlying techno–urban visions into hegemonic techno–urban strategies, projects, and initiatives as well as their institutionalization in city structures and urban practices (e.g. Bibri and Krogstie 2016a, c; Batty et al. 2012; Al Nuaimi et al. 2015; Kramers et al. 2014; Al–Nasrawi, Adams and El–Zaart 2015). As regards to the construal of smart sustainable cities, Jessop (2004, p. 164) asserts that the relative success of discursive construals, which 'can be durably constructed materially', 'depends on how… [it] and any attempts at construction correspond to the properties of the materials…used to construct social reality'. This supports the argument about the discursive–material dialectics and the prominence of discursivity and materiality to an adequate account of the reconstruction of sustainable urban transformation. Specifically, focusing on how urban politics in relation to smart sustainable cities is done in a dialectic interplay between '*discursive selectivity* (discursive chains, identities, and performance) and *material selectivity* (the privileging of certain sites of discourse and strategies of strategic actors and their mode of calculation about their "objective interests", and the recursive selection of these strategies)' (Sum 2006, p. 8) in different spatial contexts is crucial to understand why the new discourse of smart sustainable cities has been translated into concrete projects and strategies and, thus, policy orientation has been legitimated with references to it, to draw on Bibri (2015b). In all, there is a mutual dependence between semiosis and the material world, a dialectic interplay in which smart sustainable cities is constructed as an urban reality from an ontological standpoint. Semiosis refers to 'the intersubjective production of meaning' and can be viewed as an umbrella concept for discourse and language (Jessop 2004, p. 161).

The dialectic of discursivity and materiality is in turn crucial to the social construction of smart sustainable cities. This involves developing, institutionalizing, and conventionalizing this techno–urban phenomenon by the information society (specifically technologically and ecologically advanced nations) through social constructs or cultural frames, as discussed above. These constructs or frames represent models of the urban world that are created, shared, and reified through language in the form of scientific documents and academic publications. Social constructionism posits that people rationalize their experiences through models and language (Leeds–Hurwitz 2009), concrete language use. Further, social constructs or cultural frames are produced by and depend on contingent aspects of people as social selves through social practices which form objects that an array of previous and current academic discourses on cities and urban development talk about. Accordingly, the constitution and reconstitution of urban life occurs through text production and consumption processes. This is predicated on the assumption that social and cultural change (production and reproduction) occurs through discursive practices. In light of this, recent years have witnessed a proliferation of scholarly writings on the growing role of ICT of the new wave of computing in advancing urban sustainability (e.g. Bibri and Krogstie 2016a c; Batty et al. 2012), a form of semiosis which has generated the current discursive constructions of ICT of the new wave of computing for urban sustainability, as discussed above. The related magnitude and diversity of academic research has in turn given rise to smart sustainable cities as a holistic approach into urban development. This body of work continues to flourish and is consequently instigating drastic urban transformations in terms of the way the city functions and can be developed and planned. This is being fueled by the ongoing academic debates on sustainability science (e.g. Clark and Dickson 2003; Clark 2007) and its technology orientation in relation to evaluating and mitigating the unintended consequences of anthropogenic activities 'on planetary systems and on societies across the globe and into the future' (Kieffer et al. 2003), in general, and its connection with ICT of the new wave of computing in the context of urban planning and development (e.g. Bibri and Krogstie 2016a), in particular. Sustaining the momentum is also explained by the resonance of this new intellectual trend with the practices of local city governments, landscape architects, urban planners, infrastructure companies, research institutions, sustainable development institutes, policy makers and networks, and ICT industry consortia. These corroborating aspects pertain to smart sustainable urban development studies, projects, initiatives, strategies, and policies taking place in ecologically and technologically advanced nations across the globe.

4.7. Smart Sustainable Cities in Local Social and Cultural Contexts

The foreground of the normative facet of smart sustainable cities goes with the grain of the discourse of smart sustainable urban development that plays a shaping role in the debate on such cities. In the urban context, the word 'sustainable' as a socially constructed concept essentially concerns normative values, and hence implies a certain desired state of the city or the trajectory of urban development. In a similar vein, the word 'smart' has been seen as an intended outcome (e.g. Hollands 2008; Kitchin 2014; Allwinkle and Cruiskshank 2011), rather than as an instrumental concept. As such, it becomes just as normative as sustainable (e.g. Höjer and Wangel 2015). Arguably, this conclusion can not be that simple, as what is smart is not necessarily sustainable (see Section 4.14. for further discussion).

Regardless, while there is an ongoing debate about whether theories can travel, which has resulted from the long tradition of urban politics studies (e.g. Judge, Stoker and Wolman 1995), it is widely acknowledged that many of the urban theories apply to different contexts (e.g. American cities versus European cities) (Clarke 2006; John 2001). Accordingly, it is possible to discuss a universal form of urban sustainability as underpinned by the existing large body of research in the field, but it may not be the case when speaking about the smartness of urban sustainability given the paucity of research in this regard. As the discourse on the necessity of cities being smart sustainable is present in many ecologically and technologically advanced nations, we still need to reformulate what city politics and policy is about in different contexts. On this note, urban sustainability performance is not necessarily linked to or indicated by the number of smart initiatives launched in a given city project, but these initiatives could reflect certain efforts made to improve sustainability (see Neirotti et al. 2014). In their recent study, Al–Nasrawi, Adams and El–Zaart (2015) concluded with reference to smart sustainable cities that what smartness means in different urban contexts is a subject of an ongoing theoretical debate, and there is a gap in knowledge as to the holistic assessment of smartness in such cities. In relation to this argument, it is worth pointing out that the social context (factors, elements, and actors) is essentially the crucible for ICT development and innovation in terms of which kind of new

technologies and their novel applications are more embedded—and hence more promoted—than others in different local social and cultural contexts. This relates to social studies of technology (e.g. Geels 2005; Smith 2003), an approach which analyzes the topic of technological development and innovation and focuses rather on specific technologies which are embedded in local social and cultural contexts. This approach therefore highlights that the established socio–technical regimes and strategies can induce and support the transformation of socio–technical constellations (industry associations, research communities, technological innovation systems, policy networks, etc.) towards certain goals at the macro level, to draw on Bibri (2015b), e.g. advancing urban sustainability by focusing on energy efficiency technology. Socio–technical regimes refer to 'interconnected systems of artefacts, institutions, rules and norms' (Berkhout, Smith and Stirling 2003, p. 3).

In relation to urban sustainability, however, the intellectual challenge facing the city pertains to the idea that new technologies are not only developed to enable us to do and create new things and shape how we do and create them, but also to study the processes of their own implementation and implication on the city—e.g. smart sustainable cities and their actual role in advancing sustainability. This is predicated on the assumption that 'technology and society are shaped at the same time in a mutual process', i.e., the former develops dependently of the latter, thereby affecting each other and evolving in that process (Bibri 2015b). As succinctly put by McLuhan (1964), we shape technology and thereafter it shapes us. This is the kind of challenge that needs to be resolved in the development of smart sustainable cities that will improve their contribution to sustainability and thus enhance the quality of life of their citizens. Future ICT is said to unleash the kind of science that can be mobilized to instigate profound changes (Batty et al. 2012).

In all, ICT represent social constructions, and thus related uses are inherently social and cultural (e.g. Bijker, Hughes and Pinch 1987; Bibri 2015b) but also local. And one implication of this is that there will be many ways of using and applying new technologies to address the challenge of urban sustainability and thus a diversity of smart sustainable urban projects and strategies as to the future of smart sustainable urban development. In view of that, there will be varied propositions about what makes a city, or how to make urban living, smartly sustainable. It is crucial that ICT in relation to urban sustainability takes into account the local social and cultural context where ICT is embedded and its evolution is determined. This is critically important in order to mitigate any uncertainty and risk with respect to ICT development and innovation in the direction towards advancing urban sustainability in its own context.

4.8. Knowledge/Power Relations, Scientific Discourse, and Legitimation Capacity

In common with discourses, especially academic/scholarly ones, is that they have power implications in that they constitute or form what is held as knowledge and what this entails in terms of truth effects (e.g. Foucault 1972; Burr 1995; Phillips and Jørgensen 2002; Bibri 2015b). With that in mind, the emergence, success, and continuous expansion of the discourse of ICT of the new wave of computing for urban sustainability and thus smart sustainable cities can be explained by the power effects engendered by the knowledge body pertaining to the link between computing, ICT, sustainable development, and sustainability science as scientific fields. There is therefore clear interrelation between this discourse (as a form of knowledge) and power. Foucault (1991, cited in Gordon 2000, p. i–xli) asserts that there is constant articulation 'of power on knowledge and of knowledge on power. We should not be content to say that power has a need for a certain discovery, a certain form of knowledge, but we should add that the exercise of power creates and causes to emerge new objects of knowledge and accumulates new bodies of information…The exercise of power perpetually creates knowledge and, conversely, knowledge constantly induces effects of power'. Accordingly, the power effects induced, and hence the power exercised, by the knowledge underlying ICT of the new wave of computing for urban sustainability has created new objects of knowledge in the ambit of smart sustainable cities, e.g. smart design and planning, smart sustainable urban forms, and smart urban metabolism. This will lead to new bodies of information whose accumulation in the form of concrete knowledge will induce new effects of power. And again, as this power gets exercised, it will generate new objects of knowledge. Therefore, the discourse of ICT of the new wave of computing for urban sustainability is strongly affected by the establish knowledge/power relations on the information society (specifically technologically and ecologically advanced nations).

Furthermore, academic discourses play a significant role in reshaping modern cities due to the power associated with the scientific knowledge implicated in their formation. It follows that this knowledge/ power relations determine the success and expansion of the discourse in question—in this period of history—in the ambit of smart sustainable cities. Specifically, what lies beneath this discourse in terms of its translation to concrete urban projects and strategies, institutionalization in urban practices, urban dissemination, and urban acceptance are the power effects engendered by the underlying—scientific— knowledge. The exercise of power in this context is manifested in instigating and unleashing drastic transformations to the physical, architectural, infrastructural, operational, functional, socioeconomic, and environmental aspects of the city, which consequently generates new objects of knowledge that are practically useful—in the context of sustainability. This implies that the scientific knowledge involving innovative urban technologies and their novel applications and services will continue to reshape how the city functions, and this as a result will stimulate research in urban computing, applied urban science, urban informatics, big data city analytics, and various forms of pervasive computing as scientific and technological fields. This will be determined by how successful the infolding smart urban practices will be in advancing urban sustainability. This entails to what extent advances in ICT of the new wave of computing will reshape how citizens construct their lives in relation to, and thus understand and value, sustainable urban living. Currently, ICT of the new wave of computing has had some intended effects on the contemporary city and hence demonstrated an adequate body of successful practices in relation to several urban domains and systems, as discussed above. In all, the basic idea is that the understanding of the relation between the scientific knowledge and power associated with the discourse of ICT of the new wave of computing for urban sustainability is crucial to understand the development and functioning of this discourse (in the information age and society) in connection with smart sustainable cities.

In addition, the dominance or prevalence of the discourse of ICT of the new wave of computing for urban sustainability is determined by the sheer scientificity (the application of scientific methodologies and principles) pertaining to the underlying disciplines and fields, namely urban computing, environmental science, sustainability science, sustainable development engineering, sustainability measurement, applied urban science, and so on. Their synergy and integration entail a 'legitimization capacity due to their association with the scientific discourse, [which is] one of today's main sources of legitimacy and authority in knowledge–making, decision–making, and policy– making.' (Bibri 2015, p. 138) Thanks to this legitimization capacity, ICT of the new wave of computing for urban sustainability plays a major role in the discourse of smart sustainable cities. What makes it even more powerful is that it plays a key role in the interaction between urban planning and design, sustainable development, sustainability science, computing, and ICT, as it establishes a link between these academic discourses and the scientific discourse. Over the past few years, there has been significant interest in adopting smart urban planning approaches to support the process of advancing urban sustainability through smartening sustainable cities as well as improving smart cities (e.g. Bibri and Krogstie 2016b; Kramers et al. 2014; Batty et al. 2012; Shahrokni et al. 2015; Murray, Minevich and Abdoullaev 2011; Batagan 2011)

All in all, the success of ICT of the new wave of computing for urban sustainability is associated with the exercise of power for the view of having a scientific and technical grounding (coupled with constitutive and transformational effects) due demonstrably to its potential to not only catalyze and boost sustainable urban development, but also to understand, monitor, analyze, and plan the city to improve its contribution to sustainability based on scientific and technical processes. This entails a wide variety of novel applications and services spanning over several urban domains and systems, the focus of the next section. It is thus safe to argue that it is successful and will expand for many years to come for it is practically useful to the exercise of power. Foucault's conception of knowledge/power relation suggests that knowledge is valuable and necessary to the exercise of power due to the fact that it is of practical use, not because of its truthfulness and accuracy or the opposite (Gordon 2000). However, 'urban sustainability is a complex, multidimensional matter. Conspicuously, ICT solutions alone, no matter how innovative they can get and how intelligently they can be used, cannot solve the current environmental crisis in cities… Hence, there is a need for alternative interdisciplinary research directions and innovations that may be more effective in achieving the goals' of sustainable development (Bibri 2013, p. 74). Moreover, there are many open issues that need to be addressed in the pursuit of these goals (see Bibri 2013 for an overview). This relates to the debate over techno–fixes

which will not save the environment (Huesemann and Huesemann 2011). This issue is analyzed and discussed in Section.

4.9. Productive and Constitutive Force of ICT of the New Wave of Computing for Urban Sustainability

The increasing adoption of UbiComp, AmI, the IoT, SenComp (as discursive elements of the discourse of ICT of the new wave of computing for urban sustainability) in modern cities, supported by the ongoing intensive research, development, and innovation in pervasive computing (e.g. Bibri and Krogstie 2016b, c; Shepard 2011; Lee et al. 2008; Batty et al. 2012; Kyriazis et al. 2014) reflects the productive and constitute force of these new technologies in relation to urban sustainability, among others. Implying a drastic shift in such dimensions as citizens and urban entities as users of new technologies, the prevalence of novel applications and services across diverse urban domains, and the urban players involved, coupled with the scale of the emerging ICT industry consortia and urban markets, ICT of the new wave of computing for urban sustainability as a productive and constitutive network operating on all urban scales not only produces new objects of knowledge (in the form of sciences, disciplines, fields, philosophies, and rationalities), but also generates technological artifacts, orientates technological innovations, steers technological investments, catalyzes transformations, shapes institutional developments, constitutes institutional bodies, and regenerates and creates new urban environments in the ambit of smart sustainable cities. This power manifested in a productive and constitutive network runs through the whole urban body, to draw on Foucault (1980).

Remaining on the same topic, huge investments are being funneled into smart sustainable city projects and initiatives and considerable resources are being mobilized for smart sustainable urban planning studies and research in big data in relation to city analytics and planning. The evolving expansion of ICT of the new wave of computing for urban sustainability through particularly the proliferation and expansion of smart sustainable city projects and initiatives demonstrate increasing returns and benefits from the adoption of UbiComp, AmI, the IoT, and SenComp as new technologies in diverse urban domains. These technologies benefit from the provisioning of new applications and services in response to new urban market demand as well as to the growing intention of capturing further and invigorating the application demand for the urban sustainability solutions and approaches that ICT of the new wave of computing can offer. This signifies that these technologies exhibit positive feedbacks such that the more they are deployed and implemented (in relation to smart sustainable cities), the more likely they are to be further deployed and implemented (see, e.g., Arthur 1989; North 1990). Social apparatuses 'behind this phenomenon commonly entail network effects, scale, adaptation, and learning, which fuel or stimulate further adoption of such technologies.' (Bibri 2015b, p. 140) New urban policies supporting research and innovation within urban ICT of the new wave of computing 'are increasingly being developed and more of policy networks are being formed because of the benefits expected or estimated to be gained from the significant opportunities for' (Bibri 2015b, p. 140) UbiComp, AmI, the IoT, and SenComp in relation to improving the urban model in terms of sustainability, efficiency, and the quality of life (e.g. Batty et al. 2012; Al Nuaimi et al. 2015; Shepard 2011; Lee et al. 2008; Kyriazis et al. 2014; Bibri and Krogstie 2016b, c). Adding to this is the projected wider deployment of these technologies in smart sustainable cities of the future.

4.10. The Dialectic Link Between Societal Structures and Smart Sustainable Cities

It is important to recognize the interplay between smart sustainable cities, the defining context of ICT of the new wave of computing for urban sustainability, and the links to politics and urban processes of policy and regulation. This relates to one of the theoretical arguments advocated by STS that scientific knowledge plays an important role in politics, policy making, and regulation of new technologies (UbiComp, AmI, the IoT, and SenComp as advanced solutions for sustainability). Political action is of critical importance to the emergence and functioning of smart sustainable cities as both a techno–urban discourse and a system of innovation systems. Indeed, political practice is at the core of the theory of discourse (e.g. Foucault 1972; van Dijk 1998; Fairclough and Wodak 1997) and of the theoretical framework of innovation system (e.g. Rånge and Sandberg 2015; Chaminade and Edquist 2010; Kemp 1997; Kemp and Rotmans 2005) in terms of the shaping role of politics and policy in the production and evolution of discourses and socio–technical systems governing new technologies or innovations, respectively. As drastic techno–urban transformations, smart sustainable cities, which

represent a set of complex socio–technical systems and a cluster of interrelated discourses, can not proceed without parallel political action. From a discursive perspective, political processes are at the core of material mechanisms and practices in terms of translating the visions of smart sustainable cities into concrete projects and strategies and their institutionalization in urban structures and practices (see Sum 2006). And from an innovation system perspective, political processes represent the set–up under which dynamic networks of urban actors and entities can interact within diverse industrial sectors in the development, diffusion, and utilization of knowledge and technology pertaining to urban development.

Political action shapes the emergence, insertion, and functioning of smart sustainable cities. This kind of urban transformation has a quite strong governmental and policy support, particularly in ecologically and technologically advanced nations (e.g. Al Nuaimi et al. 2015; Al–Nasrawi, Adams and El–Zaart 2015; Rivera, Eriksson and Wangel 2015; Kramers et al. 2014; Bibri and Krogstie 2016c). It figures in many policy documents and agenda as well as political statements and argumentations, in addition to being used by many institutions (e.g. industry, universities, research institutes, etc.). Policy makers explicitly refer to such meta-discourses as global sustainability and knowledge–based society when trying to legitimize smart sustainable city politics. It is not an element closed in the 'ivory tower' of research community, but it is influenced by the ongoing macro–political practices in connection with sustainable development and ICT innovation. The whole premise is that recommendations for urban shifts to smart sustainable cities are implausible to proceed without parallel political practices. As a corollary of its dynamic interaction with discourses, politics forces their emergence, insertion, and evolution (see Foucault 1972). We intend to outline some of the key facets of the operations that link the creation and evolution of the discourse of smart sustainable cities and political action.

The first mechanism utilized by political action that promotes and makes function the discourse of smart sustainable cities is the creation of regulatory and policy instrument and incentives. A driver for smart sustainable cities is to comply with environmental and socioeconomic improvement emerging as an outcome of government regulations and legislations. These as hard structural factors, have an important role to play in shaping the way smart sustainable city practices are performed and maintained. However, since appropriate policy and regulatory frameworks are necessary to achieve urban change and alter urban development behavior, governments need to construct the most cost–effective approaches. Hence, new policy designs and instruments necessitate in–depth cost–benefit analysis to promote smart sustainable cities.

The second mechanism is associated with assigning scholarly roles and/or institutional positions to particular organizations, thereby authorizing them and legitimizing their actions as to conducting R&D activities pertaining to, for example, big data in city analytics and innovation in various forms of pervasive computing, contributing to technology and innovation policy formation, and constructing new techno–urban visions, and so on. This mechanism relates to 'regimes of truth' in the sense that ecologically and technologically advanced societies have, drawing on Foucault (1972), their 'general politics of truth, i.e. the historically specific mechanisms which both produce discourses and make them function as true in particular times and places, as well as enable one to distinguish the status of actors that are charged with saying and advancing what counts as true knowledge…and thus have the legitimacy to hold or create new discourses.These regimes of truth are supported by discursive formations, the regularities that produce discourses [sciences, disciplines, fields, etc.], and made true through discursive practices [e.g. scientific reports and academic publications], through which social and cultural reproduction and change take place.' (Bibri 2015b, p. 83).

Government involvement in smart sustainable city projects and initiatives is a third mechanism by which political action forces the emergence and insertion of smart sustainable cities. This is manifested in such actions as funding ICT innovations for urban sustainability, providing positive incentives to urban markets, encouraging utilization of smart and data–centric applications that improve sustainability, advocating adoption of environmentally friendly services, greening environmentally–unfriendly urban sectors, and stimulating debates over the need to smartening sustainable cities and incorporating the goals of sustainable development into smart cities. In the context of smart sustainable cities, the role of policy making is seen in forums and symposiums, in national programs, and in local environmental programs and comprehensive plans (Höjer and Wangel

2015). So, governments direct their efforts towards creating a conducive and enabling environment for large–scale urban innovations that contribute to the global urban transformation of the city.

Lastly, political action contributes to mainstreaming smart sustainable cities by accumulating and preserving the related body of knowledge as well as disseminating and teaching their principles. This is typically carried out inside centers for research and innovation and higher educational institutions, and in specific research areas, such as smart sustainable cities and ICT for sustainable urban development. The interest in smart sustainable cities is spilling out into the wider urban sustainability education, and initiatives intended specifically to support and foster smart sustainable urban development are burgeoning, as evidenced by the schools introducing new modules (e.g. big data analytics, urban simulation models, smart urban metabolism, smart grid, smart healthcare, smart energy, and smart transport) into sustainable urban development in universities and research institutes.

The shaping role of political action in the development and evolution of smart sustainable cities is also of focus in national innovation system studies. This implies that these cities have to conform to government regulations and policies on the national level. A national innovation system can be described as a set of distinct institutions whose interactions and relationships lead, through incentive structures, competencies, collective learning, and networks, to the development, diffusion, and utilization of knowledge and technology, and which provide frameworks that enable governments to formulate and implement policies to influence innovation activities (e.g. Metcalfe 1995; Edquist 2011). In theory, the evolutionary patterns underlying national systems trigger or instigate innovation processes, as they generate interactive dynamics among organizations (Bergek et al. 2010; Edquist 2011; Freeman 1995; Lundvall 1992; Nelson 1993), which pertain to changes in technologies, institutions, and corporate strategies. In a nutshell, it is the political history that shapes the industrial structure of most, if not all, innovation systems. Accordingly, regulatory, policy, and institutional frameworks are regarded as means for influencing interactive dynamics among organizations, such as shifting technological innovative focus from unsustainable to sustainable production, sustainable energy use, and sustainable services (e.g. Bergh 2007; Chaminade and Edquist 2010; Kemp 1997; Kemp and Rotmans 2005). They therefore constitute driving forces or incentive structures of transformation to new technologies for urban sustainability and related institutional systems. Institutional frameworks are necessary to alter relations and linkages among innovative actors, and thus play an important role in shaping the way such technologies are diffused and evolve. Institutional changes are expected to be 'behind most, or at least many, of the technological changes that reduce environmentally unfriendly effects... Institutions created and modified within the framework of the political…system are typically formulated in a way that distinguishes between public and private ownership and therefore also how public organizations are managed versus how private corporations are handled' (Rånge and Sandberg 2015, p. 4).

There are diverse political mechanisms used by political action to enable and spur smart sustainable cities and what they entail in terms of new technologies. They entail such governance arrangements as funding schemes, research management, innovation and technology policies, regulatory standards, market manipulations by the state, public–private partnerships, and so on (Bibri 2015b). Arguably, these mechanisms influence in different ways the functionality of ICT of the new wave of computing for urban sustainability and thus smart sustainable cities as systems of innovation systems, and the degree of the influence is contingent upon such societal factors as the relation to established technologies, political culture and agenda, policy designs, institutional behavior, industrial leadership, and economic conditions. In light of this, smart sustainable cities should not be conceived of as an 'isolated island' or seen as a natural layer of scientific organization (see Bibri 2015b). Rather, they represent social constructions whereby seamless webs of societal factors and actors shape the emergence, development, uptake, and evolution of the underlying ICT of the new wave of computing for urban sustainability. The related new technologies represent innovative technological strategic niches within the evolving sustainable technological regimes embedded in the wider socio–technical landscape of ecologically and technologically advanced nations (see, e.g., Rip and Kemp 1998; Smith 2003; Geels 2005).

Similarly, smart sustainable cities, the defining context for ICT of the new wave of computing for urban sustainability, affect the social structures that surround them. They tend to engender changes in sociopolitical institutions and cultural shifts associated with the link between ICT innovation and

26

sustainability, as well as bring about qualitative changes in urban industry strategies, structures, and operations with respect to smart sustainable urban projects and comprehensive plans. Challenges to technological regimes emanate from, at the micro level, the development of a wide range of sustainable technologies and their smart applications and services, and their implementation in urban domains and strategies to meet the needs of urbanites. ICT of the new wave of computing for urban sustainability are 'reconfiguring the broader socio–technical landscape and providing insights for policymakers into pathways for the transformation of institutions and.. [urban] practices to mitigate or avoid environmental crisis.' (Bibri 2014, pp. 37–38) Likewise, smart sustainable cities 'will be boost to new forms of policy analysis and planning in the information age, and the greatest impacts of new technologies will be on the way we organize ourselves in cities and the way we plan this organization.' (Batty et al. 2012, p. 483). This will continue to evolve as smart sustainable urban development practices and ICT innovations for urban sustainability get further adopted and implemented, and their influence keep on gathering momentum towards reshaping unsustainable technological regimes in the ambit of smart sustainable cities. Within social studies of new technologies, which are concerned with the transformation of technological regimes, it is emphasized that innovative technological strategic niches play a role in transition governance (Rip and Kemp 1998; Smith 2003; Geels 2005) 'Often debated in reference to sustainable development as an alternative model of environmental governance and its possible use as an approach to change, transition governance aims to [drawing on Rotmans, Kemp and van Asselt (2001) and Meadowcroft (2009)] direct the gradual, continuous transformational process of socio-technical practices and socio-political landscapes from one equilibrium to another.' (Bibri 2015b, p. 183). Another strand of work within social studies of new technologies centers on 'innovative experiments in alternative, sustainable technological niches and draws lessons from the challenges they face in the context of a dominant, unsustainable technological regime' (Smith 2003, p. 128). These niches are seen as 'nurturing socio–technical configurations, which grow and displace incumbent regime activities' (Berkhout, Smith and Stirling 2003, p. 9). However, it 'remains to be seen if these changes will be…realized and maintained and sustainable technological niche activities will go mainstream… To realize a full potential of sustainable technologies depends on whether or the extent to which they will solve the bottlenecks and fiascos inherent in the existing technological regimes' (Bibri 2014, p. 38) in the realm of smart sustainable cities.

4.11. The New Urban Era: the Rapid Extending of ICT of the New Wave of Computing and the Potential for Advancing Urban Sustainability

The analytical account of STS presented thus far provides useful insights into understanding how ICT of the new wave of computing as a form of S&T directed for advancing urban sustainability has emerged from a variety of perspectives and becomes interwoven with politics and policy—urban dissemination and acceptance—under what is labelled 'smart sustainable cities' within technologically and ecologically advanced nations. One implication of this is that a new urban era characterized by computerized and data–centric faces of cities is materializing and evolving. Visions of future advances in S&T (predominantly computing and ICT) inevitably bring with them wide–ranging common visions on how cities as both forms for human settlements will evolve in the future, and the opportunities to benefit from as well as the potential risks to face (see Bibri 2015b). Important to underscore on this note is that the prevalent ICT visions of pervasive computing and their amalgamation as a new development in ICT explicitly propose to transform the city by fully computerizing it and rendering it completely data–centric. This is in contrast to what earlier developments in ICT did: transformed cities as side effects (unintended outcomes), without having the explicit goal of transforming cities. Conspicuously, the technological developments as envisioned by Mark Weiser in 1991 are being pushed through largely unnoticed across major cities all over the world by the public and other diverse urban entities and extending quite rapidly into everyday urban life and space. This is happening on the periphery of urbanites' consciousness. By all indicators, one can conclude that there is an unshakable belief in the development of cities towards ubiquitous, ambient, sentient, and/or Internet–of–everything kinds of urban environments, with computer intelligence completely infiltrating the systems and processes of modern cities on several spatial scales, thereby technology receding into the background of urban life. These indicators involve the numerous ongoing and intended urban projects and master urban plans of the so-called smarter cities as information society initiatives, smart sustainable city programs, smart urban metabolism implementations, ICT foresight studies, urban planning policies, ICT industry consortia for smart cities, research in big data analytics and context–aware computing, and development of new urban sensing technologies and

computing platforms (e.g. Batty et al. 2012; Bibri and Krogstie 2016b, c; Al Nuaimi et al. 2015; Shepard 2011; Böhlen and Frei 2009; Kyriazis et al. 2014; Shin 2009; Lee et al. 2008; Townsend 2013; Kramers et al. 2014; Shahrokni et al. 2015; Bibri 2015b). Today, the informational urban landscapes entail pervasive data sensing, data storage facilities, big data and context–aware computing platforms, urban intelligence functions and simulation models, and communication and networking capabilities. These prepare the ground for a complete infiltration of urban environment with even more smart, interacting, and interconnected devices that are said to collaborate to provide information and services to urbanites at any time and at any place. Besides, the common claim made about future cities is that they will become sentient, ambient, ubiquitous, and Internet of everything (e.g. Böhlen and Frei 2009; Crang and Graham 2007; Shepard 2011; Thrift 2014; Shin 2009; Lee et al. 2008; Kyriazis et al. 2014), as they will be loaded with ICT and resultant extensiveness and profusion of data. In fact, the city development in this direction is happening and increasingly fueled by ICT of the new wave of computing. In other words, the increasing convergence and amalgamation of emerging urban ICT is producing new faces of cities, which are characterized by deep embeddedness of ICT in the form of ubiquitous sensor technologies, computing infrastructures, data processing platforms, and wireless communication networks into urban environments. The initiatives of these cities in several countries across Europe, the USA, and Asia are increasingly considered as national urban development projects that center on strengthening the role of ICT in (sustainable) urban planning and development (see Bibri and Krogstie 2016c). Coupled with this evolving development of cities is that as instances of S&T advances, the fields of UbiComp, AmI, the IoT, and SenComp, 'are increasingly gaining legitimacy as academic pursuits, influence in industry circles, and strong support from [governments] and the business community.' (Bibri 2015, p. 215) Therefore, the prospect that computer intelligence will permeate urban environments and be in the most varied scenarios of everyday urban lives, providing new forms of urban intelligence functions, advanced big data analytics capabilities, new urban services, and drastic urban transformations is fast becoming the new reality. For more evidence on the rapidly evolving incorporation of ICT of the new wave of computing into our everyday lives, the reader is directed to Bibri (2015b).

The construction of UbiComp, AmI, the IoT, and SenComp landscapes and spaces is rapidly progressing and spanning across several spatial scales and geographical locations, not least in technologically and ecologically advanced nations. This is being boosted by the advance and prevalence of the core enabling technologies of the various forms of pervasive computing. The prospect of cities getting smarter is becoming the new reality with the massive proliferation of intelligent sensing, computing, and networking devices across various spatial scales (see Shepard 2011). This is paving the way for smartening existing sustainable cities in terms of their contribution to sustainability and improving existing smart cities in terms of their incorporation of the goals of sustainable development (e.g. Bibri and Krogstie 2016b; Höjer and Wangel 2015; Kramers et al. 2014; Batty et al. 2012; Neirotti et al. 2014). The motivation is to capture further and invigorate the application demand for the solutions for urban sustainability that ICT of the new of computing can offer. Besides, in the near future, urban sensing, big data analytics, context–aware computing, and wireless communication networks using the core enabling technologies of Ubicomp, AmI, the IoT, and SenComp will be the dominant mode of monitoring, understanding, probing, assessing, and planning the city to eventually improve sustainability, efficiency, and the quality of life (Batty et al. 2012; Bibri and Krogstie 2016c).

4.12. Smart Sustainable Cities as a Desired Goal for Future Urban Planning and Development

Over the past few years, the impetus behind the process of smartening sustainable cities and improving smart cities has been to lay the foundation for a holistic approach to urban planning and development, thereby the emergence of the concept and development of smart sustainable cities. This is further stimulating new research endeavors towards unlocking the potential of ICT of the new wave of computing for advancing urban sustainability and instigating urban projects in the same direction. The concept and development of smart sustainable cities has come to the fore as a promising response to the challenges and goals of sustainable development (e.g. Bibri and Krogstie 2016a; Höjer and Wangel 2015; Al–Nasrawi, Adams and El–Zaart 2015)—by developing smart and innovative solutions for improving sustainability, optimizing efficiency of operations and services, and enhancing the quality of life. This can occur through connecting and harnessing urban systems and assessing their performance; eliminating redundancy in urban operational functioning and service provision; and

pinpointing which domains, networks, and facilities are crucial to couple, coordinate, and integrate. The smart and innovative solutions directed towards improving different dimensions of urban sustainability have proven track records as to enhancing many processes that operate and organize urban life (e.g. Shahrokni et al. 2015; Neirotti et al. 2014; Kramers et a. 2014; Batty et al. 2012; Al Nuaimi et al. 2015; Bibri and Krogstie 2016c). It is claimed that in smart sustainable cities that the key to a better urban life—which is said to be held by ICT—will be most evidently demonstrated. Smart sustainable cities will be the incubators, generators, and transmitters of innovative ideas and smart solutions for solving the challenge of sustainability.

Therefore, the concept and development of smart sustainable cities are rapidly gaining momentum as a holistic approach to urban planning and development and as an academic pursuit, not least in technologically and ecologically advanced nations. That is to say, it is increasingly becoming an important concept not only in urban policymaking, but also in urban research and planning, generating worldwide attention as a powerful framework for strategic sustainable societal development. Especially, in more recent years, smart cities have been criticized for their lack of incorporating sustainability (e.g. Höjer and Wangel 2015; Bibri and Krogstie 2016a) and sustainable cities for their inadequate contribution to sustainability (e.g. Jabareen 2006; Kärrholm 2011; Bibri and Krogstie 2016a), in addition to a lack of connection between smart cities and sustainable cities (e.g. Kramers et al. 2014). For an extensive interdisciplinary literature review on the field of smart and sustainable cities in terms of its state–of–the–art research, the reader is directed to Bibri and Krogstie (2016a). In all, the idea of smart sustainable cities is seen as an innovative urban planning and development strategy that enables the decoupling of high quality of life from energy consumption and environmental impact. The best cities are ones that support the generation of innovative ideas and, more importantly, promote sustained development (Jacobs 1961). Besides, we live in a world where ICT has become deeply embedded into the very fabric of the contemporary city, and for sustainable cities in this world to prospers, they also need to, as advocated by many urban and environmental planning analysts, embrace what ICT of the new wave of computing has to offer as innovative solutions and sophisticated methods for advancing sustainability in order for such cites to become smart in making urban living more sustainable in many years to come.

4.13. Main Categories of Discourse about Smart Sustainable Urban Development

There are various categories of discourse about smart sustainable urban development to look at when pursuing questions pertaining to the design, development, and planning of smart sustainable cities of the future. In this context, the discursive categories are aimed at providing insights into understanding the ways in which urban issues are socially constructed in terms of the combination of smartness and sustainability, i.e., the grounds of the claims that smart sustainable cities can make cities intelligently more sustainable. Based on an extensive interdisciplinary literature review on smart and sustainable cities (Bibri and Krogstie 2016a) and extrapolating from earlier research within sustainable cities (and) smart cities (Rapoport and Vernay 2011; Joss 2011; Jabareen 2006; Höjer and Wangel 2015; Neirotti et al. 2014; Batty et al. 2012; Kramers et al. 2014; Bibri and Krogstie 2015a), it appears that both particular aspects of the planning and design of smart sustainable cities and the way these are governed (e.g. citizen science and civic participation and engagement) are part of the underlying claims. On this note, at this stage of the development of smart sustainable cities, among the urban practice challenges include strategies for strengthening both the capabilities of city governments regarding ICT solutions as well as governance and planning models (Höjer and Wangel 2015). In particular, the organization of smart sustainable cities entails a reconsideration of which kinds of actors should be involved in city governance and planning (e.g. Anthopolous and Vakali 2012; Kramers et al. 2014; ITU 2014). At the core of this is how citizens are engaged in, and actively shape, decision–making processes. Batty et al. (2012) point out that the urban sustainability issues and quality of life will be dealt with using more effective models and simulations which entails an active engagement of a wider group of citizens in novel ways in the planning of their cities; in the information age, the city will be a determining factor for shaping policy analysis and planning, and the new technology will be a salient factor for planning forms of social organization. However, the issues around the design, planning, and governance of smart sustainable cities are subject to much debate among urban planners and designers as well as academics and policymakers. And among smart sustainable cities, to extrapolate from existing research on sustainable cities and smart cities (Bibri and Krogstie 2016a), there will be both convergences and divergences around the way in which these

issues can be addressed. Yet, a convergence on a particular way of addressing the issues of the planning, design and governance of smart sustainable cities would allow to identify what it means to be, or should be, a smart sustainable city. These issues can be pursued by looking at the categories of discourse about smart sustainable urban development. These categories are elucidated below.

In terms of sustainability category, much of the discourse on sustainability speaks about it as entailing environmental, social, and economic dimensions, which ideally—in the fullest sense—should be in balance [created and maintained by sustainable development processes] for reaching the long–term goal of sustainability (Bibri 2015b; Bibri and Krogstie 2016a). Will that actually be the case in the future smart sustainable city projects, will one dimension dominate, or will those dimensions be loosely integrated? While this is for the future to tell, in sustainable cities (e.g. compact city and eco–city); social and environmental goals continue to play second fiddle while economic goals and priorities remain at the core of planning (e.g. Hofstad 2012; Bibri and Bardici 2015). It seems that urban planners supported by urban scholars and urban policymakers will, for many years to come, face difficult decisions about how they set priorities as to, and where they stand on, protecting the environment, promoting economic development, and supporting social equity in the city. Hence, they will deal with deep–seated conflicts among these three essential goals, notwithstanding the optimistic view that new procedures are likely to emerge and develop that strengthen the influence of social and ecological goals over urban planning and development practices. Given the complexity and nature of the tension engendered among those three goals, sustainable development strategies cannot be adopted completely nor can sustainability be reached fully, but only partially and approximately, respectively. This can occur through a sustained period of reflective thinking about existing societal models, accepting unavoidable changes, and confronting and resolving rather unshakable conflicts. Indeed, the value of sustainability 'lies in the long–term goals of a socio–ecological system [human society within the biosphere] in balance: society strives to sustain the ecological system along with the economic system and social system. Hence, as a goal set far enough into the future, sustainability allows us to determine how far away we are from it and to calculate whether (and how) we will reach it.' (Bibri 2013, p. 8) Nonetheless, of importance to consider from the perspective of smart sustainable urban development is that for the diverse ICT in smart sustainable cities to function requires a concerted action guided by a coordinating body with varied roles and competences in order to strategically assess the implications of ICT investments (see Höjer and Wangel 2015), and steer ICT innovations in ways that resonate with the process of sustainable urban development towards achieving the long–term goals of urban sustainability.

Regarding the category of smart sustainable city as a model, considering that the smart sustainable city is an emerging and quite ambitious model of urban development, it can be seen by the citizens and actors involved as something that can bring new opportunities for and new dimensions to the urban life. The smart sustainable city could epitomize a novel model of urban living to the world, something to break through to the mainstream and thus be replicated in different places across the globe.

As to the category of computing technology and urban design, the idea revolves around how smart sustainable city can advance and achieve sustainability. In considering ongoing smart sustainable city endeavors (e.g. Kramers et al. 2014; Shahrokni et al. 2015; Bibri and Krogstie 2016c), or existing smart and sustainable urban projects, the potential associated with smart technological solutions entails different contexts of use. In terms of energy efficiency, as a common example, ICT can be integrated with renewable solutions by incorporating smart devices to enable the operation of renewable energy technologies (e.g. Griffiths 2008). Also, ICT can be used to minimize the demand for energy resources or combining smart devices and passive solar design, one of the strategies through which sustainable urban forms can be achieved. In this regard, interaction between urban structures and energy systems (using ICT tools) should take place on every spatial scale from the city, neighborhood, and district to the building (e.g. Jabareen 2006). Another use of ICT is associated with smart urban metabolism (e.g. Shahrokni et al. 2015). Other uses of smart technological solutions relate to transport efficiency and refinement, environmental management and monitoring, mobility effectiveness, ecosystem service provisioning, quality of life enhancement, and so on (e.g. Bibri and Krogstie 2016c; Batty et al. 2012; Al Nuaimi et al. 2015). In all, there are a number of smart technological solutions that can be applied to urban activities and processes for improving sustainability, optimizing efficiency, and enhancing living standards. Such solutions depend on smart sustainable urban planning and on smart sustainable city projects that governments may implement in

collaboration with ICT companies. In this regard, a competence of a coordinating body is needed to scrutinize offers (or turnkey solutions) from ICT companies, in addition to strategically assessing the overall outcomes of ICT investments in this direction (Höjer and Wangel 2015).
.
Concerning the category of urban sustainability by design and planning or governance and management, the focus is on the contribution of design versus governance to achieving urban sustainability in smart sustainable cities. In terms of design and planning, these cities may view sustainability as an outcome of endeavors undertaken during the design and planning phase and the extent to which smart ICT is emphasized as to its merger with sustainable urban forms: a city is a smart sustainable city because it has been designed and planned as such. As to governance and management, becoming a smart sustainable city may be contingent upon the way it will be governed and managed during and after the completion of smart sustainable urban projects: a city is a smart sustainable city because it is in its development and operation governed and managed as such.

As regards to the actors driving smart sustainable cities, the idea pertains to the actors that should be involved in the development of such cities, which is crucial for understanding their vision with regard to urban sustainability. Cities as social fabrics and backbones of civilization are the result of dynamic, intertwined, and multifaceted collaborations and networks of relations between and among people, communities, organizations, institutions, universities, governments, and other entities, with the aim of generating, disseminating, and implementing smart ideas and innovative solutions. As complex systems par excellence in light of the complex scientific and technological areas involved in their planning, smart sustainable cities entail a deep understanding of, and much of collective learning about, urban problems and systems. Therefore, they are developed through collaborative decisions and guided by a multitude of actions involving various players, i.e., multilevel, poly–centric governance–based processes of planning and development. These have become even more complex through the very sophisticated technologies being used to understand, monitor, probe, assess, and plan them as urban systems (see, e.g., Batty et al. 2012; Bibri and Krogstie 2016b, c). In all, numerous kinds of actors are involved in the development of smart sustainable cities as large–scale urban planning projects and comprehensive plans, including government, public sector, private sector, citizens, communities, civil society, academia, and expert advisors. And each actor has a role to play, which may depend on, or be completed by another actor, as to shaping, planning, developing, organizing, operating, and assessing the smart sustainable city projects and initiatives.

4.14. Environmental Risks: the Multidimensional Effects of New Technologies

ICT of the new wave of computing has a number of potential risks and uncertainties in relation to environmental sustainability that need to be understood when placing high expectations on and marshalling resources for developing and deploying smart sustainable cities. There exist 'intricate relationships and tradeoffs among the positive impacts, negative effects, and unintended consequences for the environment', flowing mostly from the development, use, and disposal of UbiComp, AmI, the IoT, and SenComp technologies throughout the city (Bibri 2015b) A recent wave of research within smart cities concerns itself with the risks and other negative implications of ICT solutions. Of more focus are the risks such cities pose to environmental sustainability (e.g. Greenfield 2013; Hollands 2008; Colldahl, Frey and Kelemen 2013) due to the ubiquity and massive use of ICT. Driving also this line of research are questions involving the way smart cities should measure and identify risks, uncertainties, and hazards (e.g. Batty et al. 2012). All these issues relate to the philosophical perspective of sustainability framework. From this perspective, Brown (2012) contends that sustainability science must involve the role of technology in as well aggravating the unsustainability of social practices (e.g. urban development) as in tackling the problems such practices generate, and also the study of the societal structures as to material consumption. Huesemann and Huesemann (2011) argue that increasing material consumerism, which has been enabled by S&T, failed to bring benefits. Bibri (2015b) provides a detailed analytic account of the implications of ICT of the new wave of computing as advances in S&T for environmental sustainability. In relation to this, Huesemann and Huesemann (2011) demonstrate that technological optimism is grounded in ignorance, leading to uncritical acceptance and adoption of new technologies. This involves, to some extent, the application of new technologies to smart sustainable cities as urban development practices. Arguably, it is difficult to estimate the potential of ICT for environmental sustainability in a more meaningful way in the ambit of smart sustainable cities, as advanced ICT solutions involve

technological innovation systems embedded in much larger socio-technical systems in which a web of factors and actors other than merely scientific and technical potential tend to govern or come into play. The point is that whether in relation to urban development or other social practices, ICT involves adverse environmental impacts, which has been a subject of much debate for more than a decade. This pressing environmental issue pertains to the footprint of ICT sector whose own emissions are increasing exponentially due to the the growing demand for its advanced applications and services being offered by UbiComp, AmI, the IoT, and SenComp (e.g. Bibri 2015b). Related to the continuous development, application, and diffusion of new technologies there are a lot of myths and oxymora that apply to the ecological subsystem of the city where debates focus on the question of whether ICT of the new wave of computing can advance ecological sustainability. The adverse environmental effects of new technologies are multidimensional, complex, and intricate. They include the following:

4.14.1. Constitutive Effects

Constitutive effects derive from the deep embeddedness of ICT of the new wave of computing in the very fabric of the city–urban systems, structures, and practices, to draw on Bibri (2015b). The is due to the fact that UbiComp, AmI, the IoT, and SenComp are integrative technologies in nature by becoming an integral part of almost every urban function, activity, and domain (e.g. Batty et al. 2012; Bibri and Krogstie 2016c). Hence, constitutive effects are too complex and intricate to tackle. As new technologies become a vital e–infrastructure for the city, providing the key basic infrastructures for all vital urban processes and functions, they will dramatically increase energy consumption needed to operate the city and maintain its functioning and hence concomitant environmental risks due to the dynamics of urban development. Their effects on the city as to the environment will evolve to the point of complete dependence for which there will be a penalty to pay in terms of devouring energy as an externality to the constitutive effects of new technologies.

4.14.2. Rebound Effects

It has been acknowledged that advanced ICT solutions result in increased energy use and thus environmental impacts instead of rationalizing or decreasing it often in other parts of the energy system, which relates to rebound effects (see, e.g. Kramers et al. 2014; Bibri 2015b). Such effects are the most challenging to come to grips with, as they involve socio–economic, socio–behavioral, and socio–psychological factors. Advanced ICT improves the efficiency of the energy systems operating industrial machineries and engines as well as optimizes the production processes of the industrial plants and facilities that produce new technologies (UbiComp, AmI, the IoT, and SenComp) and their applications, products, and services as well as energy efficiency technologies based on sophisticated computational functionalities enabled by new technologies (context awareness, intelligence, decision support, etc.). This improvement, which results in reduced manufacturing costs and prices and thus increased purchasing power, leads to more demand for new technologies and their applications and services given their environmental and economic gains (as well as social benefits) in the context of smart sustainable cities. This leads to more negative impacts on the environment with the consequent production and use of new technologies and their applications, products, and services. Similarly, an optimization of energy efficiency through new ICT applications (e.g. Herring and Roy 2007) (based on computational processes pertaining to AmI, the IoT, and SenCom) often results in an increase in energy consumption as a consequence of energy savings. For example, AmI provides a lot potential to develop technologies that optimize energy efficiency and lower pollution (ISTAG 2003). Efficiency of energy resource decreases its price, which in turn results in increased demand and consumption of that resource that takes back all of the realized efficiency gains (e.g. kramers et al. 2014). To further complicate the matter, energy efficiency triggers further ICT innovation and hence more production, distribution, adoption, and disposal of energy efficiency technologies across urban sectors. Therefore, 'GHG emissions reductions enabled by more advanced energy efficiency technology are likely to be minor, if not worsened, in the absence of parallel measures to manage demand for energy, which would in the normal course of events continue to increase due to the improvement in the performance…of energy efficiency technology [enabled by]…the evolving [technological] trends' (Bibri 2015b, p. 173). In a nutshell, while advanced ICT applications allow for energy efficiency, energy savings and thus GHG emissions reductions are lost to greater energy consumption, thereby the failure to securing any efficiency gains. For other types of more complex rebound effects (time and space), the reader is directed to van den Bergh (2011). Also, Nair, Gustavsson and

Mahapatra (2010) provide an overview of the factors (social norms, income level, energy prices, perception of energy cost, education, past investment, etc.) that influence energy efficiency investments in residential buildings as one of the urban application of new technologies. Greening, Greene and Difiglio (2000) provides a comprehensive literature review of the rebound effects and their taxonomy. In all, it is a real conundrum to tackle rebound effects whether in relation to the acquisition of new technologies or the associated energy efficiency applications under the prevailing economic and urban practices.

4.14.3. Indirect Effects

Indirect effects arise from the use of UbiComp, AmI, the IoT, and SenComp applications and services across urban domains and systems on a wide city–scale. In this regard, 'the environmental impacts of these technologies derive from the GHG emissions resulting from the intensive use of energy required to power a myriad of invisible, distributed, networked, interconnected, interactive, and always–on computing devices embedded in all kinds of everyday objects and integrated into the… computationally augmented…[urban] environment' (Bibri 2015b, p. 173) to enable the functioning of big data and context–aware computing applications and services in the ambit of smart sustainable cities (e.g. Bibri and Krogstie 2016c; Batty et al. 2012; Al Nuaimi et al. 2015; Solanas et al. 2014). Put differently, the operation of smart urban applications requires a huge amount of energy to power sensors, data processing platforms, wireless communication networks, and pervasive computing infrastructures across the city. At issue is the design flaws inherent in the hardware and software systems of new technologies when it comes to energy consumption, as such systems are designed to be redesigned for optimizing their energy efficiency (Bibri 2015b). This is applicable to energy efficiency technologies developed based on AmI, the IoT, and SenComp functionalities. Therefore, it is important to address and overcome the challenges of the unsustainability of ICT design methods in terms of energy–intensive use and concomitant GHG emissions risks relating to the use phase of the life–cycle of ICT products and applications—considering that new technologies are projected to usher in automation in nearly all domains of smart sustainable cities, as pointed out above.

4.14.4. Direct Effects

Involving electronic components, sensors, devices, systems, processes, and infrastructures, UbiComp, AmI, the IoT, and SenComp technologies are associated with direct effects on the environment. Such effects derive from 'the design, manufacturing, distribution, maintenance, and disposal processes of… [related] products, applications, and services by the ICT industry' in terms of 'the energy used to make computer hardware and software, build facilities and maintain their operation, ship equipment, transport goods, provide multiple services'(Bibri 2015b, p. 174), and recycle e–waste. Adding to this is the material resource depletion in terms of extracting huge amounts of heavy metals and scarce elements, in addition to hazardous and highly toxic synthetic chemicals, water and toxic waste, electromagnetic radiation caused by wireless sensors, incineration of semiconductor–rich devices and systems, and so on (Bibri 2015b). This relates likewise to the design flaws inherent in the hardware and software components and systems of ICT due to many factors, including obsolescence, lack of incentives to design out e–waste, and lack of interest to adopt green design or sustainable product design (e.g. Forge 2007; Greenpeace 2005; Datschefski 2001; Abraham and Nguyen 2003). However, the direct effects of new technologies on the environmental will exacerbate due to the increasing demand for their applications, products, and services in relation to smart sustainable cities as an emerging urban development strategy.

4.14.5. Systemic Effects

The challenge of systemic effects is of a real dilemma in smart sustainable cities for it is unlikely to be a 'magic bullet' solution for their special conundrum. The systemic effects of new technologies are the most complex of all the aforementioned effects given their dynamic, volatile, and unpredictable nature. Indeed, particularly 'direct and indirect effects—which are relatively easy to model, analyze, and evaluate – have, up to the present time, been the focus of much of the research work that has been carried out on the link between AmI[, UbiComp, SenComp,] and the IoT technologies, innovation, and environmental sustainability.' (Bibri 2015b, p. 175). Systemic effects (e.g. MacLean and Arnaud 2008; Erdmann and Hilty 2010) arise commonly from changes in social, cultural, economic, and urban

structures, practices, and behaviors enabled and triggered by the widespread adoption, ubiquitous presence, and massive use of UbiComp, AmI, the IoT, and SenComp applications, products, and services (e.g. Bibri 2015b). The changes enabled and triggered by new technologies will affect social, cultural, economic, and urban parameters in the context of smart sustainable cities as to 'the behaviors, attitudes, and expectations of consumers; citizens and communities; the demand and supply of AmI[, UbiComp, SenComp,] and the IoT services, products, and applications; manufacturing and distribution processes; organizational structures; and the various levels and forms of governance' (Bibri 2015b, p. 175). These parameters are linked to the constitutive effects of new technologies considering their deep embeddedness in the fabric of the city and thereby changing how it operates and evolves. Seen from this perspective, the choices and decisions made by all urban constituents, including citizens, communities, organizations, and institutions 'about how to use new technologies to change their behaviors and structures are unlikely to unfold or translate into behavioral and structural patterns that will play a potentially significant role in determining the possibility of a successful…[smart sustainable city] response to the challenges of environmental sustainability. All in all, what is certain is that there is no certainty as to how the environmental conundrums of AmI[, UbiComp, SenComp,] and the IoT could be tackled.' (Bibri 2015b, p. 175)

5. Concluding Remarks and Discussions

Computing and ICT are going through fast advances and dynamic paradigm shifts. They are rapidly permeating and drastically transforming the contemporary city. This study aimed to analyze the nature, practice, and impact of ICT of the new wave of computing for urban sustainability as a form of S&T, as well as to address the risks this form poses to environmental sustainability in the context of smart sustainable cities. The analytical and philosophical outcome of this work provides useful, deep insights into understanding how ICT of the new wave of computing for urban sustainability and, thus, smart sustainable cities have emerged from different perspectives. And why they have become institutionalized and interwoven with politics and policy under what is labelled 'smart sustainable cities' within ecologically and technologically advanced nations. Of importance to underscore first is that this study is a means to facilitate interdisciplinary collaboration as to various academic disciplines and theories enabled by the STS approach to provide a multifaceted, yet unified, analysis and evaluation, and thereby a more integrated and broader understanding of the topic of sustainable sustainable cities. In this regard, this study provides highly illuminating findings intended to be of interest and value to those researchers who are enthusiastic about the benefits of new technologies and/or concerned about their unintended consequences and negative effects on modern cities and the environment, and to those practitioners who intend to develop better cities into the future.

The study shows that smart sustainable cities are produced by the socially constructed understandings and socially anchored and institutionalized practices pertaining to ICT of the new wave of computing for urban sustainability and thus medicated by ecologically and technologically advanced societies. Accordingly, these cities as a manifestation of scientific knowledge and technological innovation are shaped by and also shape techno–scientific, socio–cultural, and politico–institutional structures. This implies that they represent 'social constructions whereby seamless webs of societal factors (scientific, cultural, social, historical, political, economic, legal, and institutional) shape the emergence, production, uptake, and evolution of [the underlying new] technologies' (Bibri 2015b, p. 7). Put differently, as scholarly discourses, they are inherently part of and influenced by societal structures, and produced through social practice and in social interaction. This doesn't though make them paradigmatic, but rather intellectual trends that are socio–culturally and socio–politically situated. However, the findings are in line with the theoretical perspective of sociology of scientific knowledge. This approach posits that S&T affect society, culture, and politics through scientific knowledge and its technological applications, and are, in turn, affected by social, cultural, and political conditions (e.g. Bibri 2015b). Accordingly, computing along with its ICT applications as a form of scientific knowledge are embedded in the wider social context within which they arise. The interdisciplinary field of sociology of scientific knowledge is concerned with 'the social conditions and effects of science, and with the social structures and processes of scientific activity.' (Joseph and Sullivan 1975). In connection with city–related disciplines, this field deals with the scientific knowledge underlying computing and ICT as an urban activity, i.e. the community of those who practice this scientific knowledge and its shared assumptions and ways of reasoning in relation to urban development, and conceives of it as produced by the societal structures where cities are embedded. Far from setting out to attack the scientific

endeavors, the researchers in this field aim to explain why one understanding rather than another becomes dominant and gains support and succeeds due to external societal (and historical) conditions. This theoretical argument pertains to the emergence and functioning of smart sustainable cities as jointly constructed understandings within technologically and ecologically advanced societies at this particular time of history. In all, computing and ICT as S&T develop dependently of cities as social fabrics, 'in a mutual process where they both are shaped at the same time and thus affect each other and evolve. In other words, [they]…are socially situated and mediated.' The findings are also consistent with the theoretical perspectives on the dialectic relationship between discourse and social structures (e.g. Foucault 1972; van Dijk 1998; Fairclough and Wodak 1997).

Moreover, the study demonstrates that the success and expansion of ICT of the new wave of computing for urban sustainability and thus smart sustainable cities stem from the morphing power, knowledge/power relation, productive and constitutive force, and legitimation capacity underlying computing and ICT as science and science–based technology. This is due to their association with the scientific discourse, the sheer scientificity pertaining to the underlying disciplines and fields, namely computer science, environmental science, sustainability science, sustainable development engineering, sustainability measurement, applied urban science, and so on. This finding is supported by the theory of discourse (Foucault 1972). The scientific discourse is deemed of authority with respect to decision–making and policy–making processes (e.g. Bibri 2015b) as to smart sustainable cities. This is also of relevance to the academic field of STS in that scientific knowledge plays an important role in politics, policy making, and regulation of S&T on the basis of their role in society. The scientific discourse entails different facets that intertwine to engender major societal transformations, as well as plays a role in the interaction between different coexisting academic discourses that circulate in society, as it establishes a link between these discourses, which gives rise to new techno–urban phenomena, among others.

In addition, the study corroborates that ICT of the new wave of computing for urban sustainability pose risks to environmental sustainability. Hence, it needs to be reoriented in a more environmentally sustainable direction, as they can not, as currently practiced, solve the environmental problems placed in the agenda of smart and sustainable cities as a holistic approach to sustainable urban development. This is in line with the assumption made in STS as an academic field that S&T play a role in environmental conflicts and also give rise to controversies pertaining to the natural environment. In this respect, a relevant question to raise is how and to what extent the so–called sustainability–oriented smartness can deliver the intended environmental outcomes, and prioritize between different conflicting goals. Especially, it is not an easy task to evade the conflicts among the goals of sustainable development, irrespective of the realm of its application. These conflicts cannot be shaken off so easily', as they 'go to the historic core of planning and are a leitmotif in the contemporary battles in our cities', rather than being 'merely conceptual, among the abstract notions of ecological, economic, and political logic' (Campbell 1996, p. 296). Indeed, among the challenges for smart sustainable cities include strategic assessment in terms of developing and implementing methods and practices that take a holistic approach into evaluating the effects of ICT solutions (Höjer and Wangel 2015) on the environment. Otherwise smart sustainable cities risk becoming nothing more than just an urban labelling and thereby serve politico–economic ends (e,g, Bibri and Bardici 2015), or without substantiated content (Höjer and Wangel 2015). Therefore, the value-neutrality of ICT and the ethics of its imperative are to be questioned and challenged. This relates to the argument advanced by Huesemann and Huesemann (2011) that techno-fixes will not save the environment. Rather, advanced technology is not a panacea for environmental ills. Indeed, in their book, Huesemann and Huesemann (2011) demonstrate 'why negative unintended consequences of science and technology are inherently unavoidable and unpredictable, why counter-technologies, techno-fixes, and efficiency improvements do not offer lasting solutions, and why modern technology, in the presence of continued economic growth, does not promote sustainability but instead hastens collapse.' It follows that complex problems may require simple solutions. And thereby scientific knowledge should not be inherently of higher level than other forms of knowledge (e.g. Foucault 1972). Huesemann and Huesemann (2011) argue that most problems and challenges confronting the world have inherently low-tech solutions. This raises the argument that ICT of the new wave of computing for urban sustainability is associated with 'perspectives and knowledge claims that are associated with biases and confines that need to be challenged, questioned, dismantled, and corrected in the quest for holisticized/systemic theoretical and practical knowledge. Indeed, the contingency grounding our understanding of sustainable world has implications for ruling out alternatives of thinking and acting in that world.' (Bibri 2014, p. 49)

Competing Interests

The authors declare that they have no financial and non–financial competing interests.

Funding

Authors' Contributions

SEB and JK made equally substantive intellectual contributions to the study. They have made substantial contributions to the collection, analysis and interpretation of data, have been involved in drafting the manuscript and revising it critically for important intellectual content; and have given the final approval of the version to be published.

Submitting Author's Information

SEB is a Ph.D scholar in the area of smart sustainable cities of the future at NTNU, Trondheim, Norway. His intellectual pursuits and endeavors have resulted, hitherto, in an educational background encompassing knowledge from, and meta–knowledge about, different academic disciplines. He holds a Bachelor of Science in computer engineering with a major in ICT strategy, a research–based Master of Science in computer science with a focus on ICT for sustainability, a Master of Science in computer science with a major in informatics, a Master of Science in entrepreneurship and innovation with a focus on new venture creation, a Master of Science in strategic leadership toward sustainability, a Master of Science in sustainable urban planning, a Master of Social Science with a major in business administration (MBA), a Master of Arts in communication and media for social change, a Master of Science in decision support and risk analysis, and a postgraduate degree in management and economics.

SEB's areas of research work include smart sustainable cities of the future, Ambient Intelligence (AmI), Ubiquitous Computing (UbiComp), Sentient Computing (SenComp), the Internet of Things (IoT), and how these ICT visions of pervasive computing relate to urban design and planning, urban sustainability, efficiency of urban operation and services, and the quality of life of citizens, in addition to their core enabling technologies, including sensor technologies, big data analytics, context–aware computing, cloud computing platforms, and wireless communication networks.

SEB has a genuine interest in interdisciplinary and transdisciplinary research. In light of his varied academic background, his research interests include new computing paradigms or ICT visions (i.e. AmI, UbiComp, SenComp, and the IoT), urban computing, urban informatics, big data in city analytics, urban sustainability, sustainable city models and smart city approaches (knowledge city, sentient city, ambient city, ubiquitous city, eco–city, compact city, real–time city, etc.), sustainability transitions and eco–innovations, green and social innovation of technology, philosophy and sociology of scientific knowledge, social construction and shaping of science–based technology, governance of socio–technical changes in technological innovation systems, energy efficiency technology, sustainable business model innovation, and technology and innovation policy.

SEB is the author of the following two recent books in the field of pervasive computing:

(1) The Human Face of Ambient Intelligence: Cognitive, Emotional, Affective, Behavioral and Conversational Aspects, Springer, 07/2015, 523 pages.
(2) The Shaping of Ambient Intelligence and the Internet of Things: Historico-epistemic, socio-cultural, Politico-insitutional and Eco-environmental Dimensions , Springer, 11/2015, 301 pages.

References

Abraham, M. A. and Nguyen, N. 2003, 'Green engineering: defining the principles', *Environmental Progress*, vol. 22, no. 4, pp. 233–236.

Alakeson, V., Aldrich, T., Goodman, J. and Jorgensen, B. 2003, *Making the net work: sustainable development in a digital society,* Forum for the Future, Teddington.

Allwinkle, S. and Cruickshank, P. 2011, 'Creating smart–er cities – an overview', *Journal of Urban Technology,* vol. 18, no. 2), 1–16.

Al–Nasrawi, S. Adams, C. and El–Zaart, A. 2015, 'A conceptual multidimensional model for assessing smart sustainable cities', *Journal of Information Systems and Technology Management, v*ol. 12, no. 3, pp. 541–558.

Al Nuaimi, E., Al Neyadi, H., Nader, M. and Al–Jaroodi, J. 2015, 'Applications of big data to smart cities', *Journal of Internet Services and Applications,* vol. 6, no. 25, pp. 1–15.

Anthopolous, L. G. and Vakali, A. 2012, 'Urban planning and smart cities: interrelations and reciprocities' in F. Álvarez, F. Cleary, P. Daras, J. Domingue and A. Galis, (eds.), *The future internet.* SpringerVerlag, Berlin, Heidelberg, pp. 178–189.

Arthur, W. B. 1989, 'Competing technologies, increasing returns, and lock–in by historical events', *The Economic Journal,* vol. 99, pp. 116–131.

Batagan, L. 2011, 'Smart cities and sustainability models', *Informatica Economica,* vol. 15, pp. 80–87.
Batty, M. 2005, *Cities and complexity: understanding cities with cellular automata, agent based models, and fractals,* MIT Press, Cambridge, MA.

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., Ouzounis, G. and Portugali, Y. 2012, 'Smart cities of the future', *The European Physical Journal*, vol. 214, pp. 481– 518.

Bergh J. C. J. M. 2007, *Evolutionary economics and environmental policy: survival of the greenest,* Edward Elgar, Cheltenham.

Bergek, A., Jacobsson, S., Hekkert, M., Smith, K. 2010, 'Functionality of innovation systems as a rational for and guide to innovation policy', in R. Smits, P. Shapira and S. Kuhlmann (eds), *The theory and practice of innovation policy: an international research handbook*, Edward Elgar, Cheltenham, pp. 115–144

Berkhout, F., Smith A. and Stirling, A. 2003, 'Socio–technological regimes and transition contexts', SPRU Electronic Working Paper Series 106.

Biagioli, M. (ed.) 1999, *The science studies reader*, Routledge.

Bibri, S. E. 2013, 'ICT for sustainable urban development in the European Information Society: a discursive investigation of energy efficiency technology', Master Thesis, School of Culture and Society, Malmö University.

Bibri, S. E. 2015a, *The human face of Ambient Intelligence, cognitive, emotional, affective, behavioral and conversational aspects*, Springer–Verlag, Berlin, Heidelberg.

Bibri, S. E. 2015b, *The shaping of Ambient Intelligence and the Internet of Things: historico–epistemic, socio–cultural, politico–institutional and eco–environmental dimensions*, Springer–Verlag, Berlin, Heidelberg.

Bibri S. E. 2014, 'The potential catalytic role of green Entrepreneurship−technological eco–innovations and ecopreneurs' acts−in the structural transformation to a low–carbon or green economy: a Discursive Investigation', Master Thesis, Lund University.

Bibri, S. E. and Bardici, V. 2015, 'The Sustainability of eco–city model of sustainable urban form: green and energy efficiency technology–related framing and selectivity issues in eco–city projects in Stockholm', *International Journal of Architectural and Environmental Engineering*, vol. 2, no. 5, pp. 1–20.

Bibri, S. E. and Krogstie, J. 2016a, 'Smart sustainable cities of the future: an extensive interdisciplinary literature review', *Journal of Sustainable Cities and Society* (in press).

Bibri, S. E. and Krogstie, J. 2016b, 'Future sustainable cities: ICT of the new wave of computing for urban sustainability', *Journal of Sustainable Cities and Society* (in press).

Bibri, S. E. and Krogstie, J. 2016c, 'Big data and context–aware computing in smart sustainable cities: applications and challenges', *Journal of Internet Services and Applications* (in press).

Bifulco, F., Tregua, M. Amitrano, C. C. and D'Auria, A. 2016, 'ICT and sustainability in smart cities management', *International Journal of Public Sector Management*, vol. 29, no. 2, pp.132–147.

Bijker, W. E. 1995, '*Of bicycles, bakelites, and bulbs: toward a theory of socio–technical change*, MIT Press, Cambridge, MA.

Bijker, E., Hughes, T. and Pinch T. (eds.) 1987, *The social construction of technological systems. New directions in the sociology and history of technology*, MIT Press, Cambridge, Massachusetts, London.

Bosse, T., Castelfranchi, C., Neerincx, M., Sadri, F. and Treur J. 2007, 'First international workshop on human aspects in ambient intelligence', Workshop at the European Conference on Ambient Intelligence, 10 November, Darmstadt, Germany.

Brown, H. S. 2012, 'Sustainability science needs to include sustainable consumption', *Environment: Science and Policy for Sustainable Development*, vol. 54, no. 1, pp. 20–25.

Burr, V. 1995, *An introduction to social constructivism*, Sage, London.

Böhlen, M. and Frei, H. 2009, 'Ambient intelligence in the city: overview and new perspectives' in H. Nakashima, H. Aghajan and J. C. Augusto (eds.), *Handbook of Ambient Intelligence and Smart Environments,* Springer, New York, NY, pp. 911–938.

Campbell, S. 1996 , 'Green cities, growing cities, just cities? Urban planning and the contradictions of sustainable development', *Journal of the American Planning Association*, vol. 62, no. 3, pp. 296–312.

Caragliu, A., Del Bo, C. and Nijkamp, P. 2009, 'Smart cities in Europe', Serie Research Memoranda 0048, VU University Amsterdam, Faculty of Economics, Business Administration and Econometrics.

Carlsson, B., Jacobsson, S., Holmen, M. and Rickne, A. 2002, 'Innovation systems: analytical and methodological issues', *Research Policy*, vol. 31, pp. 233–245 .

Carlsson, B. and Stankiewicz R. 1991, 'On the nature, function, and composition of technological systems', *Journal of Evolutionary Economics,* vol.1, pp. 93–118.

Chaminade C. and Edquist C. 2010, 'Inside the public scientific system: changing modes of knowledge production', in Smits R., p. Shapira P. and S. Kehlmann (eds.), *The theory and practice of innovation policy: an international research handbook,* Edward Elgar, Cheltenham, pp. 95–114.

Clark, W.C. 2007, 'Sustainability science: a room of its own', *Proceedings of the National Academy of Science* vol. 104, pp. 1737–1738.

Clark, W.C. and Dickson, N. M. 2003, 'Sustainability science: the emerging research program', *Proceedings of the National Academy of Science USA,* vol. 100, no. 14, pp. 8059–8061.

Clarke, S. E. 2006, 'Globalisation and the study of local politics: is the study of local politics meaningful in a global age?', in H. Baldersheim and H. Wollmann (eds), The comparative study of local government and politics: overview and synthesis, Barbara Budrich Publishers, Leverkusen–Opladen, pp. 33–65.

Colldahl, C., Frey, S. and Kelemen, J. E. 2013, 'Smart cities: strategic sustainable development for an urban world', Master Thesis, School of Engineering, Blekinge Institute of Technology.

Crang, M. and Graham, S. 2007, 'Sentient cities: ambient intelligence and the politics of urban space', *Information, Communication and Society*, vol. 10, no. 6, pp. 789–817.

Datschefski, E. 2001, *The total beauty of sustainable products*, Rotovision.

Dlodlo N., Foko T., Mvelase P., and Mathaba S. 2012, 'The state of affairs in Internet of Things research', *The Electronic Journal Information Systems Evaluation,* vol. 15, no. 3, pp. 244–258.

Dryzek, J. S. 1997, *The politics of the earth: environmental discourses,* Cambridge University Press, Cambridge.

Dumreicher, H., Levine, R. S. and Yanarella, E. J. 2000, 'The appropriate scale for "low energy": theory and practice at the Westbahnhof", In Architecture, city, environment, Proceedings of PLEA 2000, ed. Steemers Koen and Simos Yannas, James & James, London, pp. 359–363.

Edquist, C. 2005, 'Systems of innovation. Perspectives and challenges', in J. Fagerberg, D. Mowery and R. Nelson (eds.), *Oxford handbook of innovation*, OUP, Oxford, pp. 181–208,

Edquist, C. 1997, 'Systems of Innovation approaches. Their emergence and characteristics', in C. Edquist and M. McKelvey (eds.), *Systems of innovation: growth, competitiveness and employment*, vol I, Elgar Cheltenham, pp. 3–37.

Edquist, C. 2011, *Systems of innovation: technologies, institutions and organizations*, Routledge, Abingdon

Edquist, C. and Johnson, B. 2000, 'Institutions and organizations in systems of innovation', in C .Edquist and M. McKelvey (eds.), *Systems of innovation: growth, competitiveness and employment*, vol II Elgar, Cheltenham, pp. 165–187.

Etzkowitz, H. and Leydesdorff, L. 2000, 'The dynamics of innovation: from national systems and mode 2 to a Triple Helix of university–industry–government relations', *Research Policy,* vol. 29, no. 2, pp. 109–123

Erdmann, L. and Hilty, L. M. 2010, 'Scenario analysis exploring the macroeconomic impacts of information and communication technologies on greenhouse gas emissions', *Journal of Industrial Ecology*, vol. 14, no. 5, p. 826.

Fairclough, N. 2005, 'Critical discourse analysis', *Marges Linguistiques*, vol. 9, pp. 76–94.

Fairclough, N., Jessop, B. and Sayer, A. 2004, 'Critical realism and semiosis', in S. Fleetwood and J.M. Roberts (eds), *Realism, discourse and deconstruction*, Routledge, London, pp. 23–42.

Fairclough, N. and Wodak, R. 1997, 'Critical discourse analysis', in van Dijk T. A. (ed.), *Discourse studies, a multidisciplinary introduction, discourse as social interaction,* Sage, London, pp. 258–284.

Fisher, K 1997, 'Locating frames in the discursive universe', *Sociological Research Online,* vol. 2, no. 3, pp. U40–U62.

Forge, S. 2007, 'Powering down: remedies for unsustainable ICT', *Foresight,* vol. 9, no. 4, pp. 3–21

Foucault, M. 1966, *The order of things: an archaeology of the human sciences*, Vintage Books, New York.

Foucault, M. 1972, *The archaeology of knowledge*, Routledge, London.

Foucault, M< 1980, 'Truth and power', in C. Gordon (ed.), *Power/knowledge, selected interviews and writings 1972–1977*, Harvester Wheatsheaf, Hemel Hempstead.

Foucault, M. 1991, 'Politics and the study of discourse', in G. Burchell, C. Gordon and P. Miller (eds.), *The Foucault effect: studies in governmentality*, The University of Chicago Press, Harvester Wheatsheaf, pp. 53–72.

Freeman, C. 1995, 'The "National System of Innovation" in historical perspective', *Cambridge Journal of Economics,* vol. 19, pp. 5–24.

Fuchs, C. 2005, 'Sustainability and the information society', ICT&S center: Advanced studies and research in information and communication technologies & society, University of Salzburg Salzburg.

Geels, F. W. 2004, 'From sectoral systems of innovation to socio–technical systems: insights about dynamics and change from sociology and institutional theory', *Research Policy*, vol. 33, no. 6–7, pp. 897–920.

Geels, F. W. 2005. *Technological transitions and system innovations: a co–evolutionary and socio–technical analysis,* Edward Elgar, Cheltenham, UK.

Gordon, C 2000, 'Introduction', in P. Rabinow (ed.), *Michel Foucault power – essential works of Foucault 1954–1984,* The New Press, New York, pp. i–xii.

Greenfield, A. 2013, *Against the smart city*, Verso, London.

Greening, L. A., Greene, D. L. and Difiglio, C. 2000, 'Energy efficiency and consumption: the rebound effect – a survey', *Energy Policy*, vol. 28, no. 6/7, pp. 389–401.

Greenpeace 2005, *Toxic tech: pulling the plug on dirty electronics*, Greenpeace International, viewed 21 April 2008,<www.greenpeace.org/international/press/reports/toxic–tech–puling–the–plug>

Griffiths, M. 2008, 'ICT and CO2 emissions', *Parliament Office of Science and Technology Post–note*, no. 319, pp. 1–4.

Gubbi, J., Buyya, R., Marusic, S. and Palaniswami, M. 2013, 'The Internet of Things (IoT): a vision, architectural elements, and future directions', *Future Generation Computer Systems*, vol. 29 pp. 1645–1660.

Hajer, M. A. 1995, *The politics of discourse: ecological modernization and the policy process*, Clarendon Press, Oxford.

Herring, H. and Roy, R. 2007, 'Technological innovation, energy efficient design and the rebound effect', *Technovation*, vol. 27, pp. 194–203.

Hess, D. J. 1997, *Science studies: an advanced introduction*, New York University Press, New York.

Hilty, L.M., Arnfalk, P., Erdmann, L., Goodman, J., Lehmann, M. and Wager, P. A., 2006, 'The relevance of information and communication technologies for environmental sustainability – prospective simulation study', *Environmental Modelling and software*, vol. 21, no. 11, pp. 1618–1629.

Hilty, L. M., Wäger, P., Lehmann, M., Hischier, R., Ruddy, T. and Binswanger, M. 2004, *The future impact of ICT on environmental sustainability*, Fourth interim report – refinement and quantification, Institute for Prospective Technological Studies, IPTS, Sevilla.

Hofstad, H. 2012, 'Compact city development: high ideals and emerging practices', *European Journal of Spatial Planning*, pp. 1–23.

Hollands, R. G. 2008, 'Will the real smart city please stand up?', *City: Analysis of Urban Trends, Culture, Theory, Policy, Action*, vol. 12, no. 3, pp. 303–320.

Höjer, M. and Wangel, S. 2015, 'Smart sustainable cities: definition and challenges', in L. Hilty, and B. Aebischer (eds.), *ICT innovations for sustainability*, Springer–verlag, Berlin, pp. 333–349.

Huang, Y., and Li, G. 2010, 'A semantic analysis for Internet of Things', Proceedings of the 2010 International Conference on Intelligent Computation Technology and Automation (ICICTA), Changsha, China, pp. 336–339.

Huber, J. 1985, *The rainbow society: ecology and social politics*, Fisher Verlag, Frankfurt am Main.

Huesemann, M. H. and Huesemann, J. A. 2011, *Technofix: why Technology won't save us or the environment,* New Society Publishers.

International Telecommunications Union (ITU), 2014, 'Agreed definition of a smart sustainable city', Focus Group on Smart Sustainable Cities, SSC–0146 version Geneva, 5–6 March.

ISTAG 2003, *Ambient Intelligence: from vision to reality (For participation – in society & business)*, viewed 23 October 2009, <http://www.ideo.co.uk/DTI/CatalIST/istag–ist2003_draft_consolidated_report.pdf >

ISTAG 2006, *Shaping Europe's future through ICT*, viewed 22 March 2011, <http://www.cordis.lu/ist/istag.htm>

ISTAG 2008, *Working Group on 'ICT and Sustainability (including Energy and Environment)'*, viewed 20 March 2012,<http://www.cordis.lu/ist/istag.htm>

ISTAG 2012*, Towards horizon 2020 – Recommendations of ISTAG on FP7 ICT work program 2013*, viewed 15 March 2012, <http://cordis.europa.eu/fp7/ict/istag/reports_en.html>

Jabareen, Y. R. 2006, 'Sustainable urban forms: their typologies, models, and concepts', *Journal of Planning Education and Research*, vol. 26, pp. 38–52.

Jacobs, J. 1961, *The death and life of great American cities,* Random House, *New York.*

Jasanoff, S., Markle, G., Petersen, J. and Pinch, T. (eds.) 1995, *Handbook of science and technology studies*, Sage Publications.

Joseph, B. and Sullivan, T. A. 1975, 'Sociology of science', *Annual Review of Sociology*. vol. 1, no. 1, pp. 203–222

Jessop, R. 1998, 'The narrative of enterprise and the enterprise of narrative: place marketing and the entrepreneurial city' in T. H. All and P. Hubbard (eds.), *The entrepreneurial city: geographies of politics, regime and representation*, Wiley*,* Chichester, pp. 77–99.

Jessop, R. 2004, 'Critical semiotic analysis and cultural political economy', *Critical Discourse Studies*, vol. 1, no. 2, pp. 159–174.

John, P. 2001, *Local governance in western Europe, Sage,* London.

Joss, S. 2011, 'Eco–cities: the mainstreaming of urban sustainability; key characteristics and driving factors', *International Journal of Sustainable Development and Planning*, vol. 6, no. 3, pp. 268–285.

Judge, D., Stoker, G. and Wolman, H. 1995, *Theories of urban politics*, Sage, London.

Kärrholm, M. 2011, 'The scaling of sustainable urban form: some scale—related problems in the context of a Swedish urban landscape', *European Planning Studies*, vol. 19, no.1, pp. 97–112.

Kates, R., Clark, W., Corell, R., Hall, J. and Jaeger, C. 2001, 'Sustainability science', *Science (Science)*, 292, no. 5517, pp. 641–642.

Kemp R. 1997, *Environmental policy and technical change: a comparison of the technological impact of policy instruments,* Edward Elgar, Cheltenham.

Kemp, R. and Rotmans, J. 2005, 'The Management of the co–evolution of technical, environmental and social systems', in Weber M. and J. Hemmelskamp (eds.), *Towards environmental innovation systems,* Springer Verlag, Berlin.

Kieffer, S. W., Barton, P., Palmer, A. R., Reitan, P. H. and Zen, E. 2003, 'Megascale events: natural disasters and human behavior', The Geological Society of America Abstracts with programs.

Kitchin, R. 2014, 'The real–time city? Big data and smart urbanism', *Geo Journal*, vol. 79, pp. 1–14.

Kramers, A., Höjer, M., Lövehagen, N. and Wangel, J. 2014, 'Smart sustainable cities: exploring ICT solutions for reduced energy use in cities', *Environmental Modelling & Software*, vol. 56, pp. 52–62.

Kyriazis, D., Varvarigou, T., Rossi, A., White, D. and Cooper, J. 2014, 'Sustainable smart city IoT applications: heat and electricity management and eco–conscious cruise control for public transportation', Proceedings of the 2013 IEEE 14th International Symposium and Workshops on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), Madrid, Spain, pp. 1–5.

Kuhn, T. S. 1962, *The structure of scientific revolutions*, University of Chicago Press, Chicago.

Lee, S. H., Han, J. H., Leem, Y. T. and Yigitcanlar, T. 2008, 'Towards ubiquitous city: concept, planning, and experiences in the Republic of Korea', in T. Yigitcanlar, K. Velibeyoglu and S. Baum (eds.), *Knowledge–based urban development: planning and applications in the information era*, IGI Global, Information Science Reference, Hershey, Pa., pp. 148–169.

Leeds–Hurwitz, W. 2009, 'Social construction of reality', In S. Littlejohn and K. Foss (eds.), *Encyclopedia of communication theory,* SAGE Publications, Thousand Oaks, CA, pp. 892–895.

Li, S., Wang, H.; Xu, T. and Zhou, G. 2011, 'Application study on Internet of Things in environment protection field', Lecture Notes in Electrical Engineering, vol. 133, pp. 99–106.

Lindell, M. 2012, 'Do major innovation models consider unintended consequences? A review and revised framework, in K. E. Sveiby, P. Gripenberg and B. Segercrantz (eds.), *Challenging the innovation paradigm*, Routledge, London, pp. 169–185.

Lu, T. and Wang, N. 2010, 'Future Internet: the Internet of Things', 3rd International Conference on Advanced Computer Theory and Engineering (ICACTE), vol. 5, pp. 376–380.

Lundvall, B–Å. (ed.) (1992). *National innovation systems: towards a theory of innovation and interactive learning*, Pinter, London.

Lynch, K. 1981, *A theory of good city form, MIT Press,* Cambridge, MA.

MacLean, D. and Arnaud, B. S. 2008, *ICTs, innovation and the challenge of climate change*, International Institute for Sustainable Development (IISD), viewed 21 May 2009, <http://www.iisd.org/pdf/ 2008/ict_innovation_climate.pdf>

Madden, P. and Weißbrod, I. 2008, 'Connected ICT and sustainable development', Forum for the Future: Action for Sustainable World, viewed 22 April 2009, <http://www.forumforthefuture.org/files/ Connected.pdf>

Marinova, D. and Phillimore, J. 2003, 'Models of innovation', in L. Shavinina (ed.), *Handbook on Innovation*, Elsevier, Oxford, pp. 44–53.

McLuhan, M. 1964, *Understanding media: the extensions of man*, McGraw Hill, New York.

Meadowcroft, J. 2009, 'What about the politics? Sustainable development, transition management, and long term energy transitions', *Policy Science*, vol. 42, pp. 323–340.

Moscovici, S. 1984, 'The Phenomenon of social representations', in R. Farr and S. Moscovici (eds.), *Social representations,* Cambridge University Press, Cambridge, pp. 3–69.

Metcalfe, S. (1995), 'The economic foundations of technology policy: equilibrium and evolutionary perspectives', in P. Stoneman (ed.), *Handbook of the economics of innovation and technological change*, Blackwell Publishers, Oxford (UK)/Cambridge (US).

Murphy, J. 2000, 'Ecological modernization', *Geoforum* 31, pp. 1–8, Oxford Centre for the Environment, Ethics and Society, Mansfield College.

Murray, A., Minevich, M. and Abdoullaey, A. A. 2011, *The future of the future: being smart about smart cities*, KMworld, 20(9), viewed 29 January 2016, <http://www.kmworld.com/Articles/ Column/The–Future–of–the–Future/The–Future–of–the–Future–Beingsmart–about–smart–cities– 77848.aspx>

Nair, G., Gustavsson, L. and Mahapatra, K. 2010, 'Factors influencing energy efficiency investments in existing Swedish residential buildings', *Energy Policy*, vol. 38, no. 6, pp. 2956–2963.

Nam, T. and Pardo. T. A. 2011, 'Conceptualizing smart city with dimensions of technology, people, and institutions', Proceedings of the 12th Annual International Conference on Digital Government Research.

Neirotti, P., De Marco, A., Cagliano, A. C., Mangano, G. and Scorrano, F. 2014, 'Current trends in smart city initiatives – some stylized facts', *Cities,* vol. 38, pp. 25–36.

Nelson, R. (ed.) 1993, National innovation systems. A comparative analysis, Oxford University Press, New York/Oxford.

North, D. C. 1990, *Institutions, institutional change and economic performance*, Cambridge University Press, Cambridge, UK.

Piro, G., Cianci, I., Grieco, L. A., Boggia, G. and Camarda, P. 2014, 'Information centric services in smart cities', *The Journal of Systems and Software*, vol. 88, pp. 169–188.

Phillips, L & Jørgensen, MW 2002, *Discourse analysis as theory and method*, Sage, London.

Poslad, S. 2009, *Ubiquitous computing: smart devices, environments and interaction*, Wiley & Sons.

43

Rapoport, E. and Vernay A. L. 2011, 'Defining the eco–city: a discursive approach', Paper presented at the Management and Innovation for a Sustainable Built Environment Conference, International Eco–Cities Initiative, Amsterdam, The Netherlands, pp. 1–15.

Rånge, M. and Sandberg, M. 2015, 'Windfall gains or eco–innovation? "Green" evolution in the Swedish innovation system', *Society for Environmental Economics and Policy Studies*, pp. 1–20.

Richardson, N. 1989, *Land use and planning and sustainable development in Canada*, Canadian Environmental Advisory Council, Ottawa.

Rico, J. 2014, 'Going beyond monitoring and actuating in large scale smart cities', *NFC & Proximity Solutions – WIMA Monaco.*

Rip, A. and Kemp, R. 1998, 'Technological change', in S. Rayner and E. Malone (eds.), *Human choices and climate change.* vol. 2, pp. 327–99.

Riva, G., Loreti, P., Lunghi, M., Vatalaro, F. and Davide, F. 2003, 'Presence 2010: the emergence of ambient intelligence', in G. Riva, F. Davide and W. A. IJsselsteijn (eds.), *Being there: Concepts, effects and measurement of user presence in synthetic environments*, pp. 60–81, Amsterdam: IOS Press.

Rivera, M. B., Eriksson, E. and Wangel, J. 2015 'ICT practices in smart sustainable cities–*in* the intersection of technological solutions and practices of everyday life', 29th International Conference on Informatics for Environmental Protection (EnviroInfo 2015), Third International Conference on ICT for Sustainability (ICT4S 2015), Atlantis Press, pp. 317–324.

Rotmans, J., Kemp, R. and van Asselt, M. 2001, 'More evolution than revolution: Transition management in public policy', *Foresight*, vol. 3, no. 1.

Rotmans, J., van Asselt, M. and Vellinga, P. 2000, 'Assessment methodologies for urban infrastructure: an integrated planning tool for sustainable cities', *Environmental Impact Assessment review,* vol. 20, pp. 265–276.

Shahrokni, H. Årman, L., Lazarevic, D., Nilsson, A. and Brandt, N. 2015, 'Implementing smart urban metabolism in the Stockholm Royal Seaport: smart city SRS', *Journal of Industrial Ecology*, vol. 19, no. 5, pp. 917–929.

Shepard, M. (ed.) 2011, *Sentient city: ubiquitous computing, architecture and the future of urban space*, MIT Press, Cambridge.

Shin, D. 2009, 'Ubiquitous city: urban technologies, urban infrastructure and urban informatics', *Journal of Information Science*, vol. 35, no. 5, pp. 515–526.

Sismondo, S. 2003, *An introduction to science and technology studies,* Blackwell.

Smith, A. 2003, 'Transforming technological regimes for sustainable development: a role for alternative technology niches?', *Science and Public Policy,* vol. 30, no.2, pp. 127–35.

Solanas, A., Pérez−Martínez, P. A., Martínez−Ballesté, A., Patsakis, C., Conti, M., Vlachos, I. S., Perrea, D. N., Ramos V., Falcone, F., Postolache, O. and Di Pietro, R. 2014, 'Smart health: a context −aware health paradigm within smart cities', *IEEE Communications Magazine,* vol. 52, no. 8, pp. 74−81.

Sum, N. L. 2004, 'From "integral state" to 'integral world economic order': towards a neo–Gramscian cultural international political economy', CPE Working Paper.

Sum, N. L. 2006, 'Toward a cultural political economy: discourses, material power and (counter)hegemony', EU Framework 6, DEMOLOGOS project, workpackage 1.

Thrift, N. 2014, 'The "sentient" city and what it may portend', *Big Data and Society*, vol. 1, 2053951714532241.

Toppeta, D. 2010, *The smart city vision: how innovation and ICT can build smart, "livable", sustainable cities*, The Innovation Knowledge Foundation, viewed 2 February 2016, <http://www.thinkinnovation.org/file/research/23/en/Top peta_Report_005_2010.pdf>

Townsend, A. 2013, *Smart cities – big data, civic hackers and the quest for a new utopia,* Norton & Company, New York.

Uckelmann, D., Harrison, M., and Michahelles, F. 2011, *Architecting the Internet of Things*, Springer Berlin, Germany.

van den Bergh, J. C. J. M. 2011, 'Energy conservation more effective with rebound policy', *Environ. Res. Econ, vol.* 48, pp. 43–58.

van den Berg, L. M. and van Winden, W. 2000, 'ICT as potential catalyst for sustainable urban development: experiences in Eindhoven, Helsinki, Manchester, Marseilles and The Hague', European Institute for Comparative Urban Research (EURICUR), Erasmus University.

van Dijk, T. A. 1998, '18 Critical discourse analysis', viewed 28 April 2011, http://www.discourses.org/OldArticles/Critical%20discourse%20analysis.pdf.

Vermesan, O. and Friess, P. 2013, *Internet of Things: converging technologies for smart environments and integrated ecosystems,* River Publishers Series In Communications, London, UK.

Vongsingthong, S. and Smanchat, S. 2014, 'Internet of Things: a review of applications and technologies, Suranaree', *Journal of Science and Technology* (in print).

Weiser, M. 1991, The computer for the 21st Century', *Scientific American*, vol. 265, no. 3, pp. 94–104.

Weiser, M. 1993, 'Some computer science issues in ubiquitous computing', *Communications of the ACM*, vol. 36, no. 7, pp. 75–84.

Wheeler S. M. and Timothy, B. (ed.) 2010, *The sustainable urban development reader*, Routledge, London, New York.

Williams, K. 2009, 'Sustainable cities: research and practice challenges', *International Journal of Urban Sustainable Development*, vol. 1, no. 1, pp. 128–132.

Yang, Q., Wang, Z., and Yue, Y. 2012, 'Summarize the technology of the things of Internet', Proceedings of the 2012 2nd International Conference on Consumer Electronics, Communications and Networks (CECNet), April 21–23, Yichang, China, pp. 1,357–1,360.

Zheng, Y., Capra, L., Wolfson, O. and Yang, H. 2014, 'Urban computing: concepts, methodologies, and applications', *ACM Trans. Intelligent Systems and Technolies,* vol. 5, no. 3, pp. 1–55.