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# Cyber–Physical Systems in Smart Cities – Mastering Technological, Economic, and Social Challenges

*Martina Fromhold-Eisebith*

*Department of Geography, RWTH Aachen University, Aachen, Germany*



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## Objectives

- To broaden readers' understanding of the process fields of smart city development that can profit from enhanced information and communication technologies
- To explore in which respects cyber–physical systems (CPSs) may help in improving the coordinated control, regulation, and monitoring of different smart city processes, supporting sustainability objectives
- To introduce geographical perspectives into the debate on technology-driven smart city development, highlighting place-specific dynamics as well as upper-scale national and global influences on localized economic processes
- To point out risks and caveats that influence the societal acceptance of technology-driven smart city development and need to be regarded in related policies.

## 1.1 Introduction

The "smart city" notion has become synonymous with visions of future urban development, which is marked by the widespread digitization of services [1–4].

*Smart Cities: Foundations, Principles and Applications,* First Edition.
Edited by Houbing Song, Ravi Srinivasan, Tamim Sookoor, and Sabina Jeschke.

A major objective of smart cities is to achieve triple sustainability in social, economic, and environmental issues [5]. Modern information and communication technologies (ICTs), the Internet, and the continuous expansion of data supply broaden the options for improving urban citizens' working and living conditions [6–8]. This chapter explores how cyber–physical systems (CPSs) in particular may enhance smart cities. In the field of manufacturing, CPS now represents innovative options for integrating ICT and networking systems into infrastructure, so as to more efficiently control and coordinate complex physical production processes and machine interactions [9, 10]. ICT devices that are embedded into products or components are able to monitor and direct physical processes in a self-regulating manner – directly communicating with each other via the Internet. CPS also has a vast potential beyond the industrial field. Within a smart city context, these systems could significantly augment urban services and supply infrastructure. Moreover, new CPS-driven manufacturing may emerge according to the trends of "urban production" [11].

Together with the requirements and potential implications of smart cities [1, 5], policy demands associated with this visionary goal are also eagerly explored [2, 12–15]. This chapter intends to broaden the conceptual and analytical views, as is required for effective policy making, by employing the perspectives of economic geography to CPS-supported smart city development. In principle, economic geographers focus on place-specific dynamics and systemic interactions between technology trends, economic challenges, social needs, and planning requirements [16]. Localized processes are seen as being embedded in wider, often global, economic, political, and societal settings [17, 18]. Accordingly, viable CPS technologies, along with socioeconomic and cultural settings at the regional level and other spatial scales (as discussed in [2]), are required if a smart city is to reach its full potential. In this context, the chapter explores the following key issues:

- In which ways can CPS help create a technologically enhanced smart city within the context of working and living in a manner that responds to environmental, economic, and societal challenges?
- Looking at the various fields in which CPS may support smart city development, how is the effective implementation of technologies influenced by economic conditions on a regional, national, and global scale and also by social attitudes?
- How can city–regional planning approaches meet these factors in order to arrive at economically and socially acceptable, hence viable, smart city policies?

The chapter's structure reflects this agenda. After defining the system setting (Section 1.2), the author identifies various process fields of working and living in a smart city that can profit from CPS-related applications and impulses (Section 1.3). Then it is discussed how economic conditions influence effective

CPS implementation in place-specific ways (Section 1.4). Additionally, social challenges of CPS-based smart city development that relate to aspects of acceptability, qualification, and adaptation are highlighted. The conclusions (Section 1.5) derive insights for policies, suggesting how economic and social well-being can be best promoted when implementing the CPS-enhanced smart city of tomorrow.

## 1.2 Setting the Scene: Demarcating the Smart City and Cyber–Physical Systems

The range of human activities that are affected by digitization increases every day, which amplifies the scope of ICT applications in urban development. Certain system limits need to be determined before we can concisely assess potential CPS applications in smart cities. This refers both to a proper understanding of the smart city notion and the CPS technology field. Only after the arena and its boundaries have been decided upon, it is possible to succinctly identify the relevant technology options.

A smart city can be defined in various ways (Albino *et al.* [1]: 6ff, compiled a list of over 20 different definitions). Despite differing perspectives held by public or private actors, there are common denominators [3–5, 8]. A smart city is first and foremost characterized by the strategic, systematic, and coordinated implementation of modern ICT applications in a range of urban functional fields (as elaborated below). This idea of a "digital city" involves both software and hardware components, such as sensors, meters, and other technical devices. Furthermore, the generation targeted and the use of inhabitants' knowledge, learning capacities, creativity, and human capital for innovations, in line with analytical and modeling skills, qualify smart cities as "intelligent cities" [19, 20]. The notion thus transcends a technological focus and explicitly bears an anthropocentric note: smart cities aim to comprehensively fulfill people's needs in terms of economic and social sustainability, happiness, and well-being [1, 5]. The connotation "green city" highlights the ecological objectives of reduced resource consumption, constrained pollution, and high process efficiencies [21]. Shared ideology and community governance strategies are important to stakeholders, especially regarding how the outcomes manifest themselves in public and politically promoted attitudes regarding improvements to the urban quality of life. We need to keep these manifold smart city qualities in mind when assessing the prospects of CPS implementation later on.

CPS technologies build on antecedent embedded systems, that is, computer-driven devices like medical, military, or scientific instruments, cars, and toys. Accordingly, CPSs use software and ICT networks in order to control, monitor, and coordinate complex physical processes, though this is mainly applicable to modern manufacturing [9, 10]. CPS can efficiently organize production within companies and also, through communication between components and machines, coordinate the value chain between different firms. Advancing from conventional computer-integrated manufacturing, CPS incorporates elements of self-awareness and self-regulation, wireless inter-machine adjustment, and complex data processing, thus integrating information from various stages and organizations within a production system. The Internet of Things forms a crucial CPS component, as objects can now carry digital information themselves and directly communicate with other objects, such as processing machines, via the Internet [22]. The expected results are a substantially modified division of labor in manufacturing and related services, consequently a transformed production landscape [23].

Existing literature discussing smart city qualities selectively refers to CPS components [7, 24, 25]. Big data sets, that is, large amounts of data on citizens' purchasing habits, mobility, and other behaviors, call for adequate information processing technologies and the expedient use of said technology [6, 8, 26]. Intelligent products or services like thinking machines, sensor-monitored smart homes, and self-regulating infrastructure are expected to significantly shape the face of smart cities [1–3, 27] and reach far beyond simple ICT applications. It seems that due to the more systematic exploration approaches available, urban CPS applications have more potential merits and also risks. As elaborated below, CPS based on advanced ICT can promote all smart city objectives in some way and ICT is essential for a truly integrated development. Only the flexible, self-regulating CPS qualities meet the requirements for cities that want to be able to resiliently react to future challenges [28].

## 1.3 Process Fields of CPS-Driven Smart City Development

Several scholars have already categorized the process fields that constitute a smart city (overview in [1]: 11ff; [5]). Drawing on these works, and also adding further urban arenas that could benefit from "smart" enhancement, this section proposes 11 fields that have the potential for CPS-driven processes: smart ICT infrastructure, smart energy, smart mobility, smart construction, smart security, smart metabolism, smart industries, smart economy, smart education, smart living, and smart governance. Each of these fields touches upon the aforementioned smart city objectives, and the ways in which CPS applications can substantially support efficient functionality and regional sustainability will be discussed in this chapter (see Table 1.1).

The first aspect, ICT infrastructure, forms the backbone of any smart city, and no CPS can work without it. A scaffold of high-capacity computers, communication nodes, and fast connections is crucial for linking various system elements together and driving their efficient cooperation as well as

**Table 1.1** Smart City Process Fields, CPS Applications, and Sustainability Effects.

| Process fields | Functions of CPS applications | Expected effects |
|---|---|---|
| Smart ICT infrastructure | Establish broadband or wireless connectivity and communication compatibility between all urban citizens and institutions based on hardware and software components | Overarching urban network of enhanced information flows and coordination that supports system efficiency |
| Smart energy | Implementation of smart grid technologies that control energy consumption and optimize coordination between decentralized power generation and utilization of renewables | Less consumption of fossil fuels and better integration of renewable energy production, leading to higher efficiency |
| Smart mobility | Coordinated goods logistics and e-mobility modes (cars, bikes, public transport), using geographical information, enable customized transport for citizens and companies | Reduction of gas and particulate matter (PM) emissions and of traffic congestions, also diminishing noise |
| Smart construction | Setting up buildings and settlements that, through system coordination, optimize the supply of amenities, consumption of resources, and living conditions | Reducing the individual use and waste of resources; increasing living quality for individuals and communities |
| Smart security | Coordination of advanced lighting and surveillance equipment that covers urban settlement areas, public spaces, and traffic lines and is controlled according to frequencies of use | Improving the overall quality of residence and living by preventing various types of (environmental) crime |
| Smart metabolism | Organizing a circular economy (“closing the loop”) that optimizes the (re)use and recycling of resources, including water and waste management, by matching supply and demand | Less consumption of various resources, reduced emissions, and waste through functional eco-industrial networks |

**Table 1.1** (Continued)

| Process fields | Functions of CPS applications | Expected effects |
|---|---|---|
| Smart industries | Selective integration of tailor-made goods manufacture and related services into urban development ("urban production"), colocating production, and consumption | Increased diversity of localized industrial activities and job opportunities, reducing home-to-work travel distances |
| Smart economy | Targeted orientation of entrepreneurship and business development toward new fields of ICT and CPS application in order to build up modern sectors that shape future trends | Laying the foundations for future economic competitiveness and for capacities to cater to local ICT/CPS needs |
| Smart education | Dedicated inclusion of smart city–related ICT/CPS technologies in education and R&D activities that support adequate qualification and skills of people, integrating all social classes | Better preparation of people for future economic tasks and job market demands, also supporting social inclusion |
| Smart consumption | Broadening options for a sharing economy as well as public monitoring and display of environment data, activating a reflected and resource-conscious consumption behavior | Reducing the individual waste of resources; increasing social cohesion and public awareness for environmental issues |
| Smart governance | Advance and coordinate ICT-based public services to all residents ("e-government") and offer new ways to influence and take part in political processes ("e-democracy") | Better quality and efficiency of public services, broadening the participation of citizens in political processes |

*Source:* Author's depiction, partly drawing on information from Allwinkle and Cruickshank [12]; Komninos [20]; Lombardi *et al*. [29]; Matt *et al*. [11]; Neirotti *et al*. [14]; Albino *et al*. [1].

interoperability, like energy grids, mobility and logistics, and resource and waste management [14]. This field has been associated with smart city ideals right from the start, enabling all inhabitants to benefit from digital infrastructure and participate in knowledge acquisition, learning, and innovation [19, 20, 30]. The system-enhancing powers of this process field are at the heart of the notion:

> smart cities must integrate technologies, systems, services, and capabilities into an organic network that is sufficiently multi-sectorial and flexible for future developments, and moreover, open-access.
>
> (Albino *et al.* [1: 11]).

CPSs can substantially support the required coordination, openness, and flexible learning qualities of a modern ICT system [31]. None of the other smart city arenas operate in isolation, as energy and transport issues, construction, industrial development and the metabolism of resource inputs, and waste or emission outputs are intrinsically intertwined. CPSs are capable of coordinating infrastructure operation and information flows within and between these subsystems. The same holds for sensors and observational devices, like those mounted onto unmanned aerial vehicles (UAVs, or drones), which should serve various monitoring purposes simultaneously. In this context, the Internet occupies a key role as it has the potential to reach every citizen [32]. Debates concerning this process field focus on strong technology, thus involving various CPS elements: hardware and software, network solutions, extended options of advanced sensing [33], Internet of Things [7], cloud computing, ubiquitous Wi-Fi access, and real-time big data processing [8, 15, 26, 34, 35].

The interrelated dimensions of smart energy and mobility (Table 1.1) traditionally play a major role in smart city development regarding environmental concerns and sustainability objectives [5, 36, 37]. In the energy field, the installation of flexible, coordinated systems that link decentralized sources of energy production (based on photovoltaics, biogas, etc.) to individual dwellings with variable levels of energy consumption requires veritable "smart grid" solutions [11, 14]. CPSs offer important means for measuring, adjusting, and balancing energy supply in relation to demand. Likewise, visions of a "smart transport city" refer to ICT and geographical information systems that support flow management of goods and people, delivering "a self-operative and corrective system that requires little or no human intervention" [38: 48]. In addition to transport logistics coordination and intelligent structures of distribution, CPS applications enhance the monitoring and regulation of traffic flows using mobility sensors and smart parking management [1, 13]. E-mobility offers further scope for CPS utilization, matching the supply of e-transport modes, like e-bikes or Internet-connected "cyber cars," with individual "mobility-on-demand" needs [11].

The process field of smart construction is associated with customized control requirements of "smart homes" or "sustainable buildings" [39]. Objectives also include, but reach beyond, reduced energy consumption and emissions. Modern ICT applications form important elements of smart houses; the combination of various monitoring and control devices can optimize living conditions and environmental balance sheets [40]. The particular assistance demands of an aging population call for the implementation of ICT-controlled ambient assisted living technologies [41]. CPS applications were explicitly discussed as a means to improve the energy efficiency of buildings [24, 27], but they can also be useful beyond that. If entire settlements or housing clusters were equipped with CPS controls and sensors, it would be possible to create further reaching social sustainability effects by involving different households and generations of individuals. Here CPS integration may allow for energy and material flows within and between buildings. This moves city quarters toward achieving self-sufficiency and potentially turns them into hybrid energy storage systems for other parts of the city [11].

The smart mobility, smart construction, and smart ICT infrastructure fields are closely connected with the smart security process field, which is often mentioned in seminal smart city literature [1, 14, 29, 42]. Supposedly, modern observation and sensor-based surveillance technologies, in line with smart lighting installations or UAVs, significantly support the security and feeling of safety in urban citizens. CPSs aim to better combine, coordinate, and assess the information delivered by all the cameras, sensors, and environmental monitors placed in various parts of a city. The big data collection resources provided, through public Wi-Fi use, for example, may also feed into the smart security system, which in turn should be able to detect and foresee abnormal situations and potential risks [8].

Smart metabolism and smart industries (Table 1.1) refer to dimensions that have not yet received dedicated attention in smart city debates. This includes options to more efficiently organize industrial resource consumption in line with the "reduce, reuse, recycle" strategies and by establishing eco-industrial networks or parks where the waste, used water, or by-products of one industry serve as valued input for others [43]. Efficient regional material flow management requires sophisticated production planning, process monitoring, and logistics [44], all of which CPSs offers viable solutions for. Concerning the process field of smart industries, CPS technologies may also allow various manufacturing activities to return to urban locations [11]. Ongoing digitization will substantially change the methods of industrial production, in doing so establishing new combinations of advanced manufacturing and city–regional development in different parts of the world [45]. CPS applications can create extended options for "clean" production (for instance, using additive fabrication or 3D printing techniques) and bring tailor-made consumer goods production closer to the individualized demand of the open-minded, affluent urban citizen. Additionally, people profit from broadened job opportunities near their home. In general, CPS-enhanced coordination and control of industry processes may even improve the environmental impact and resource efficiency of urban production systems.

The suggested categorization of smart city process fields intentionally distinguishes between smart industries and a smart economy (Table 1.1). While the first notion looks at new ways of goods production in an urban context, the second one emphasizes new entrepreneurial opportunities that arise through the development of modern ICT and CPS technologies and importantly their adaptation to local applications [4, 29]. Companies face a diversified set of expanding business options in sectors such as engineering consulting, ICT system installation, implementation of CPS tools, big data processing, and development of mobile services and applications [46]. Growing clusters of firms primarily cater to local needs, supporting smart metabolism objectives of localized cycles of product and service delivery. Furthermore, globally competitive competences are created, which more broadly foster a city's economic sustainability.

The smart education field aims to technologically sustain and upgrade the smart regional economy. Several works emphasize the pivotal role of higher education institutions in delivering the qualifications and expertise needed to create a sustainable urban future [1, 47]. Human capital is regarded as one of the most important resources in smart city development [48, 49]. Given that major cities attract talented people from all over the world, the smart city vision promotes ideas of social inclusion across nationalities and cultures [50]. In line with education requirements for operating CPS applications, technological innovation is needed. The proclaimed openness of smart cities to communication and interaction calls for integrated skills regarding open innovation [51] and the competence to activate the triple helix university–industry–government collaboration [52]. The education system must also foster regional skills in order to purposefully interpret the big data stocks collected in a smart city. For implementing effective CPSs, qualified people who are able to derive meaningful insights from mobility, input–output, environmental, and other data sets are needed.

Finally, the process fields of smart consumption and smart governance address important sociopolitical qualities (Table 1.1). Smart city visions can only be put into practice when the majority of citizens are convinced of this idea and actively engaged in the relevant arenas of daily life [50]. Following Vanolo's logic [53], people need to develop a certain attitude toward "smart" solutions, dubbed "smart mentality." Sustainability-oriented smart consumption attitudes can grow over time and are driven by smart education. Modern ICT can also be employed in order to accelerate the achievement of sociopolitical goals. It helps make people better aware of major smart city issues in terms of environmental factors like the continuous monitoring and public display of air quality data using CPS. Furthermore, digital services enable people to actively shape a resource-efficient urban economy, for instance, through online platforms that support the local sharing of goods and services. Additionally, municipal administration can foster citizens' participative attitudes via ICT-based smart governance tools. Any smart city is expected to provide interoperable, Internet-based government services that offer ubiquitous access to public assistance. Citizens and businesses shall be enabled to closely follow, and even actively influence, government processes without barriers like language, education, or disabilities hindering them [1].

Summing up, CPSs that build on and expediently combine modern ICT appliances seem virtually indispensable in achieving the various goals of smart city development (right column in Table 1.1). Interrelatedly they can promote the economic, social, and ecological aspects of urban sustainability. The systemic, integrated, and adaptive nature of the ideal smart city and its spatially condensed options for ICT uses turn it into a perfect test site for exploring the potential benefits incorporated in CPSs. However, critical perspectives must also be taken into account.

## 1.4 Economic and Social Challenges of Implementing the CPS-Enhanced Smart City

In the large body of literature available regarding the opportunities of ICT-enhanced smart city development, hardly any critical approaches point out obstacles, caveats, and conflicting relationships between smart city process fields that could hamper smart city success [2, 50, 51]. It appears as if mankind must focus on tackling technological challenges associated with the creation of smart cities. The authors discuss how CPS "can extract the awareness information from the physical world and process this information in the cyber-world" [27, p. 1149], how to achieve data security [54], how to reduce urban CPS infrastructure risks [25], and even how devices, the Internet of things, and big data technology must be designed in order to be fit for service [6, 7, 55]. Concerning CPS technologies more specifically, issues of network functionality, efficiency, and failure prevention still need to be solved [9, 31, 56]. While these topics are crucial from an engineering perspective, we also need to highlight economic and social factors, barriers, and challenges that influence how smart cities can be realized. Academic scholars already recognized that technologies must adapt to human qualities:

> future CPSs will need to bolster a closer tie with the human element, through Human-in-the-Loop controls that take into consideration human intents, psychological states, emotions and actions inferred through sensory data.
>
> (Sousa Nunes *et al*. [57: 944])

In line with considerations regarding human adaptability to new ICT, the development of smart cities should be positioned within the context of different spatial scales of agency and decision power [2], in doing so employing institutional perspectives of economic geography [16]. Technology-oriented conceptualizations lead us to believe that the smart city just needs to emerge from its own roots, free to choose its trajectory based on endogenous assets and forces, as well as CPS preferences. The crucial role of exogenous national and global frameworks that specifically shape place-specific smart city options and patterns requires dedicated attention. Geographers regard (city) regions as spatial units marked by dynamics that reflect the interplay of upper-level influences and localized processes that are shaped by spatial proximity [17]. Accordingly, this section tries to assess how the CPS-enhanced smart city process fields are shaped by economic and social conditions in place- and scale-related ways (summarized in Table 1.2). Besides broadening conceptual views on smart cities, reasoning also offers insights for planning and policies.

By and large, the economic determinants of CPS-related smart city opportunities depend firstly on regional assets and location factors, secondly on the national framework, and thirdly on global competition [18]. Viewing the 11 smart city process fields through this lens tells us that localized assets are particularly important for implementing the basic ICT infrastructure and smart building construction and installing smart metabolism, smart industries and economy, and smart consumption. While CPS technologies may also be developed elsewhere, their customized installation and implementation in the city requires local, professional agency, and well-developed knowledge about a city's topography and functional structure. Likewise, the construction of smart homes and building clusters significantly profits from localized expertise. Regionally rooted companies know best which specialized partners nearby should be included in fulfilling the sophisticated requirements of housing settlements controlled and interconnected by modern ICT facilities [40].

In the field of smart metabolism, spatial proximity, even colocation in the same industry park, is essential for firms that want to exchange by-products and collectively use resources more efficiently [43]. Companies integrated in a CPS-coordinated material flow system can potentially reap strong economic benefits from "cash for trash" revenues and save on costs for resources, water, and waste treatment. Examples show that remarkable local marketing and reputation effects emerge from successfully establishing eco-industrial networks [58]. Smart industry strategies for utilizing CPS aim to bring production back to urban areas, and in order to better coordinate processes within and between firms, they rely on suitable location factors, such as a qualified labor market, supportive service partners, and chances to embed firms in local production systems [45]. In the cases of smart industry and smart economy, which are both driven by entrepreneurs that locally design, produce, and install CPS components, certain agglomeration and proximity advantages support

**Table 1.2** Importance of Economic Context at Different Spatial Scales and Social Acceptance for Smart City Process Fields.

| Process fields | Economic context at spatial scales | Social acceptance (++ = strong support to −− = strong opposition) |
|---|---|---|
| Smart ICT infrastructure | Regional knowledge for adopted implementation; global search for technologies | −−/+ |
| Smart energy | National energy provision systems and incentive framework for renewable energies; global search for technologies, international energy provision | ++/− |
| Smart mobility | National incentive framework and lead producers; global search for technologies; global players of production | ++/− |
| Smart construction | Regional knowledge and partner networks; global search for technologies; global players of production | −−/+ |
| Smart security | National regulation for devices, surveillance options, and data use; global search for technologies | −− |
| Smart metabolism | Regional material flows of colocating firms save transport and purchasing cost; alternative of higher value global sourcing | + |
| Smart industries | Regional factors of location, collaboration opportunities, and cluster advantages; global–local impact of CPS unclear, strong global competition in manufacturing industries | +/−− |
| Smart economy | Regional sources of entrepreneurship and business networks, cluster advantages; strong global competition in CPS technology field | ++ |
| Smart education | National systems of education and innovation; global knowledge flows and education/innovation exchanges | ++ |
| Smart consumption | Regional initiatives and communities of sharing; global cultures of sustainable living and virtual communities | ++ |
| Smart governance | National administrative requirements, incentive structures, and model initiatives | −−/+ |

*Source:* Author's depiction.

business development. Clusters of colocating firms that belong to the same value chain, for example, could potentially profit from regional interaction and knowledge collaboration as they support productivity, innovation, and competitiveness within the region [59]. A city that strategically promotes CPS-related industrial opportunities of this kind could reap high economic benefits. In the field of smart consumption, where the economic feasibility of ICT tools and services depends on large numbers of urban users, the region of residence forms the arena for joint initiatives and communities based on shared visions of sustainable urban life. Overall, the regional powers of smart city development are determined by urban population size, wealth, and qualification levels and by an industry structure that allows firms to profitably engage in CPS creation and implementation.

Quite a number of CPS-enhanced process fields, although locally installed, appear to depend predominantly on national economic conditions. The dominance of the national over the regional sphere of decision-making applies to the smart energy, mobility, security, and education fields and to smart governance in particular. Energy production and distribution by nature requires pipe and line systems that cover wider areas; therefore, it would be beneficial to combine sources at different locations and find a balance between them. While some renewable energies permit more decentralized, locally confined production (e.g., photovoltaics), their economic viability still relies on nationally determined and implemented incentives [60]. The availability of smart mobility systems, be it advanced transport logistics or e-vehicles, for urban use is also influenced by national contexts. The high prices set on these innovative products and services obstruct market success, that is, without political intervention. Similarly, the producers of mobility items add technical requirements of larger markets to national and markets of a wider scale. The same can be said for smart security, where hardware (intelligent sensors or UAVs) and software come from players operating at least at the national level. In this field, national regulations concerning permitted devices, limited surveillance rights, and data security play a crucial role. Looking at smart education, the knowledge base for human capital and innovation capacity is often formed according to national strategies and economic interests, as outlined in the national innovation system notion [61]. Finally, smart governance approaches must obey national requirements, as well as fulfill common administrative routines and functions. National governance organizations may also be influential in launching e-government incentives and initiatives.

With regard to the global scale of influence, a smart city is in principle more integrated into international goods and information flows than other cities [4, 50]. In almost all process fields, producers and users profit from effective, global research regarding suitable smart city solutions and also from embedding themselves in international supply networks (Table 1.2). In the cases of mobility and construction in particular, important global players tend to dominate the provision of high standard CPS modules. Moreover, smart industries and economies are particularly sensitive to global influences because of strong competition [17, 18]. Concerning metabolism, regionally closing the loop of material flows may not always be the most profitable option in comparison to efficient global sourcing, as local supplies may lack quality or the product might require further processing steps before use. The question of whether CPS-enhanced systems can sustain urban production in the face of global competitive pressure is debatable. Furthermore, emerging clusters of enterprises producing CPS components operate in fields where numerous regions and companies compete worldwide. Logically, smart education draws on international impulses embedded in global networks of scientific collaboration and human capital exchange [61]. Smart consumption also thrives on global trends that internationally promote sustainable lifestyles and the sharing of resources, which is only spurred on by the formation of Internet communities.

Fundamental caveats need to be raised regarding social issues associated with CPS-enhanced smart city transformation. It may be questioned as to whether large parts of an urban population are really ready to follow the “smart turn” in every aspect of their daily life – cultivating the commonly shared “smart mentality” [53]. While the practical implementation of smart city models proliferates worldwide [1, 37], a citizen’s propensity to accept or actively promote a city’s digitization still significantly varies between regions and nations. In some parts of the world, societies are generally more open toward smart city technologies than in others, as indicated by the differences between continents (with Southeast Asia taking a lead [62]) and countries, as is the case in Europe [36, 63]. The interregional differences detected through smart city benchmarking exercises clearly point at place-specific phenomena, particularly in technologically friendly and open-minded populations [64, 65].

At a city–regional level, societal attitudes are also assumed to vary according to different process fields (right column in Table 1.2). In the fields of smart security and smart governance in particular, large parts of the urban population may mistrust ICT means of control. Many people will not like an all-embracing, centrally controlled CPS infrastructure of sensors, monitors, and hovering UAVs, which in fact form the backbone of many smart city dimensions. Equally smartly constructed houses and intelligent settlements could heighten inhabitants’ suspicions about increased monitoring and automatic self-regulation, or smart buildings could simply expect too much of the technical skills of their inhabitants. In the smart industry field, fears that CPS implementation leads to rationalization and abolition of jobs could cause opposition in large sectors of society, institutionalized and amplified through trade unions. The new options created by urban production, CPS manufacture, and maintenance selectively benefit a small group of people with specific skills.

The field of smart education in turn plays a key role for promoting CPS-enhanced smart city transformations. It is unequivocally associated with affirmative societal attitudes and allows for the inclusion of all social groups. It also generally conveys broader acceptance for essential urban sustainability objectives, like those pursued in the smart consumption field and generally profits from being driven from the bottom up by the people themselves. Smart education also provides opportunities for achieving crucial ICT- and CPS-related qualifications that promote other process fields, most notably the technology-driven entrepreneurship of a smart economy, which substantially enriches regional industry structure. The fields of smart energy and mobility, which already offer socially acknowledged sustainability benefits, can also profit from a highly educated population in well-paid jobs. Smart cities need people who cherish the high societal value of a good environment in order to introduce CPS-coordinated energy and mobility solutions, which may be more expensive and make life less comfortable than previous non-smart components. The positive influences of education may over time also affect all other process fields that initially saw social opposition, such as smart infrastructure, construction, and governance. Finally, slightly more positive social attitudes can be expected in the smart metabolism field, which, except for regional cycles of smart consumption, will not visibly affect people's daily life.

## 1.5 Conclusions: Suggestions for Planning the CPS-Driven Smart City

This chapter explores how visions of smart city developments could potentially profit from using CPS applications in order to enhance system efficiency. Eleven process fields are identified, in which intelligent hardware- and software-based monitoring, control, and sensing tools can substantially improve system coordination and self-regulation, thus supporting the creation of the sustainable, environmentally friendly city of tomorrow. CPS draws on modern ICT to facilitate the alignment and communication of different devices, vehicles, buildings, companies, and people. Geographical information systems, the Internet, and wireless smartphone technology offer ample potential for the development of smart urban solutions. Besides taking up dimensions previously associated with the smart city notion, such as enhanced ICT infrastructure, energy, mobility, security, and governance [1, 3], this chapter highlights further industry-related process fields that have previously been overlooked. This includes the fact that CPS can improve resource-efficient material flow coordination within and between value chains, revitalize sites of urban production, and expand entrepreneurial opportunities.

Furthermore, the chapter explains how the process fields of CPS-enhanced smart city formation are embedded in wider economic contexts on a regional, national, and global scale, and it also raises issues of social acceptability. It is crucial to bring up more skeptical considerations in order to counterweigh the often overly optimistic attitudes expressed in most smart city literature [11, 12, 15]. Works mainly depict diverse technological possibilities and close their eyes to limited human capabilities and the level of compliance necessary for the utilization of these new technologies. Employing a critical perspective to socioeconomic factors shows that some smart city process fields may be much easier to implement regionally than others, whose introduction, for example, may face societal barriers. Policies that intend to support the CPS-driven smart city should take these insights into account and adjust activities to the differentiated set of conditions in order to better achieve their goals. Several cases have already shown how important flexible policies and institutional constellations are for installing smart city elements in urban spaces [2, 42, 66].

It seems advisable to start by promoting initiatives through which modern ICT applications directly and openly improve people's working and living conditions without enacting too much regulation or control. Smart education performs a key role as it conveys qualifications, job opportunities, and attitudes that support CPS integration in all other smart city fields. A major objective must be to diminish digital divides between the various groups that compose urban society. In line with impulses through ICT- and CPS-oriented (spin-off) entrepreneurship and intelligent urban production, smart education can set into motion a functional, self-reinforcing smart city innovation ecosystem [67]. Citizen community activities and grassroots movements aiming to bring about sustainable living through smart consumption deserve dedicated technological support right from the start. Together, this setting helps overcome societal opposition and skepticism against the installation of comprehensive ICT infrastructure required for all process fields and importantly forms the backbone of a smart city. By promoting highly visible aspects likely to affect the citizens' quality of life, CPS directs monitoring and coordination tools to factors that are significant for improving the sustainability and resource efficiency of mobility and energy systems. This applies also to the provision of user-friendly e-government services and public information on urban environmental quality, which could be used to further motivate smart consumption. These foundations can then facilitate the growth and buildup of CPS-enhanced regulations and control in the system arenas of smart construction and material flow metabolism in eco-industrial parks. As citizens may for the most part oppose the widespread implementation of smart security surveillance and ubiquitous governance, related smart technologies should only be installed with the highest degree of sensitivity and through engagement with public communication channels.

Planning and implementing the various CPS-supported processes requires participants to bear in mind that decisive conditions of smart city development are set on the national, and sometimes global scale, rather than on the directives of city–regional authorities and actor groups. Recently, Angelidou [2] highlighted the related policy issues by discussing, among other things, the "national versus local strategy" choice. Moving on from that, smart city policies should fruitfully combine factors determined at different spatial levels, just as it seems viable to combine regional, national, and global assets in order to adequately promote innovation systems [61]. Initiatives clearly rooted in the locality and favored by proximity or cluster advantages, like those relating to smart consumption, economic entrepreneurship, and material flow, can expediently be connected with national initiatives. Often only national funding, incentives, and innovation efforts make sophisticated CPS solutions for renewable energy, mobility, or security systems possible, as is the case with related programs in higher education. Urban mobility and energy systems form part of a larger setting and need effective external connectivity. Yet, regional authorities should be ready to continuously learn about and locally adapt to these options, taking advantage of regional knowledge and networks that help customize ICT facilities and smart housing settlements. The technologies and skills that sustain the evolution of CPS-enhanced smart cities are definitely of a global nature [4, 20], which demands local authorities to closely follow international trends in all related fields. When promoting the fields of smart industries and economy locally, global competition should not be ignored.

In all these endeavors, actors must be patient and let processes emerge over time without forcing the urban population because

> the path to becoming a smart city is not a sprint. It is a marathon. Or, even an ultra-marathon. […] Smart city officials realise that they need to begin by focusing on solving the most pressing issues facing their cities, but also need to have a longer term view of the end goal.
>
> (Taylor [68])

Only integrated planning that takes care of economic as well as social contexts and purposefully uses assets beyond a regional scale will create truly sustainable smart cities that make the best use of CPS applications.

## Final Thoughts

Exploring technological and socioeconomic underpinnings of smart cities, this chapter provided a list of 11 process fields in which CPS, which enable intelligent hardware- and software-based monitoring, control, and regulation of urban activities, can improve system coordination and self-regulation. It was shown that CPS better connects devices, vehicles, buildings, companies, and people as well as improves resource-efficient material flow coordination, revitalizes urban production, and expands entrepreneurial opportunities. Employing perspectives of economic geography, the chapter pointed out the place-specific nature as well as interdependencies of regional, national, and global economic contexts for smart city development. It discussed issues of societal acceptance for CPS-enhanced, digitized urban activities and, finally, suggested how smart city planning and policies should deal with the socioeconomic challenges.

## Questions

1 How can CPS be defined and what are the origins of this notion?

2 In which respects can CPS improve living and working in smart cities?

3 What qualifies a geographical perspective on technology-driven smart city development?

4 Which smart city process fields are most strongly influenced by national and global economic dynamics?

5 Why and in which ways should smart city policies account for societal barriers of CPS-enhanced smart city development?

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