Chapter 8

Life Cycle Insights for Creating Sustainable Cities

Getachew Assefa

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.81633

Abstract

The chapter focuses on the full life cycle of material and energy flows and uses in cities. Most of the impacts and opportunities in making cities more sustainable exist in how and what types of materials and energy source are used. The life cycle perspective of materials used in buildings and infrastructure systems is better addressed at the point of planning and design. The energy aspect touches both the efficiency of utilization and the impact intensity of the energy used to power and heat urban spaces and fuel transport systems. The type of sources of upstream supply of materials and energy is thus crucial. The commendable efficiency measures targeting the operation phase of urban systems should be accompanied by a consideration of the embodied impact of materials used and the end-of-life management of the materials following the end of their service life. The chapter ends with recommendations on best practices that potentially leverage on life cycle assessment results. It also covers the merits of employing the social life cycle perspective together with the environmental life cycle and economic life cycle in a life cycle sustainability assessment framework that seeks to define the triple bottom line space of lower unsustainability conditions.

Keywords: life cycle assessment, life cycle sustainability assessment, climate change, greenhouse gases, circular economy, sustainable cities, material flows

1. Introduction

Addressing increasingly pressing global challenges of climate change and other long-term impacts demands critical understanding of the sustainability (environmental, social, and economic) performance of current best practices of developing and managing the totality of urban infrastructure systems and accounting for how future technical and nontechnical changes influence the sustainability of cities. Dominant practices currently focus only on one aspect of the sustainability (e.g., environmental [1]) or only one component of the city at a time (e.g., transportation [2]) or only part of the life cycle of the infrastructure (e.g., embodied energy [3]). Decisions based on such partial information and limited knowledge should be replaced by more complete knowledge as a basis for decision analysis of the development and management of future infrastructure systems in cities to curb damaging and costly suboptimal developments. A comprehensive account of relevant environmental, social, and economic aspects of our urban systems provides municipalities and high levels of government with the opportunity to look at the merits, synergies, and trade-offs associated with alternative development and operational decisions in creating sustainable cities.

What does a sustainable city look like? The literature offers as little on a widely accepted definition of sustainable city as it does on what sustainable development in general is. The difficulty of defining sustainable development has led to over 200 definitions [4].

Closer examination of the literature over the past 20 plus years shows that different issues are emphasized in the urban sustainability discourse depending on field of study and the problem at hand. Land-use system as a vehicle for achieving urban sustainability was not widely supported with evidence as mentioned in work published in 1997 [5]. When areas where improved environmental performance is needed in cities were identified, the emphasis was on how to integrate them with social, economic, and political goals of sustainable development [6]. In a case study on the Scottish capital of Edinburgh [7], a work on weak and strong sustainability measures for cities differentiated between unsustainable cities, weak sustainable cities, and strong sustainable cities. The strong sustainable cities model is close to what is now promoted as urban scale equivalent of circular economy at the majority of materials reused, repaired, and recycled, recognizing the limits to resources and assimilation capacities (e.g., see [8]).

The literature around sustainable cities reflects the compact city concepts of abating urban sprawl, increasing density, and achieving mixed uses while ensuring diversity and vitality, both socially and economically [9]. Urban form is an important element that has attracted significant research attention in the literature. Policies that focus on sustainability of cities should stay away from the quest for a long-term goal of creating a single definitive urban form that is sustainable as it does not exist [9]. There are more avenues that lead to more sustainable forms. In their research that involved many British cities on the role of urban form, their conclusion was that “there are no simple answers or clear relationships between urban form and the dimensions of the sustainable city.” Others have also explored how density and other urban forms relate to sustainability (e.g., [10]).

Two important aspects of urban sustainability are the issue of system boundary and the issue scale. Allocation of greenhouse gases (GHGs) from surface and air transportation spatially to cities that make up a commuter shed is demonstrated in [11]. Factors such as surface vehicle miles traveled per capita (estimated to range from 13 to 129 km/capita/day for the Denver commuter shed) that affect the allocation are identified. Along the same line, geography, urban form, and the urban economy affect the GHG emissions of cities were highlighted elsewhere [12].

http://dx.doi.org/10.5772/intechopen.81633

While liveability of cities is seen within a broader framework of urban sustainable development [13], the role of sufficiently incorporated urban natural areas in creating sustainable cities is also stressed [14]. Sustainable cities are also presented in different studies as low-carbon cities (e.g., [15]). As part of achieving sustainable development of Chinese cities, low carbon goals of urban development are proposed by local governments [16]. Governance level is considered a critical element in other parts of the world as well [17–19]. They provide the examples of "garden city, Chinese electric valley, and Sun City." Examining how the concepts of compact city, the zero-carbon eco-city, and the U-ecocity contradict or fall short of meeting sustainability principles, the use of the term "transition toward the sustainable city" was proposed as an accurate and more effective goal of our cities around the world aspire to be [20]. Arguments for establishing guiding principles at different levels in creating sustainable cities are abundant (e.g. [21, 22]).

The literature is full of connecting the concept of sustainable cities to the triple bottom line of social, economic, and environmental standing of different aspects of urban areas. The need to convert our unsustainable cities by developing sustainable city models and rehabilitation plans that help us implement sustainability practices considering environmental and social performance factoring in economic elements is pointed out [23]. Earlier, the social, economic, and environmental dimensions of urban sustainability feature both complementarity and contradiction, underlining the importance of investigating alternatives using a holistic approach [9]. Even much earlier, going beyond the triple of bottom line of social, economic, and environmental sustainability, the n-bottom line framework of performance attributes used in the research, development, and demonstration activities under the sustainable cities research theme at CSIRO, Australia, was presented [24].

Overall, there is a recognition that cities are better supported with improved sustainability-oriented policy-relevant information and knowledge on urban design, development, and management (e.g., [25]). There are potential multiple features that can represent what can be considered as part of the sustainable city vision [26].

From a life cycle perspective, a sustainable city is here defined as one whose residents and decision-makers account for a life cycle triple bottom line (social, economic, and environmental bottom lines) performance in prioritization and ranking of alternative decisions emphasizing the process. A sustainable city as a product is one that advances socially and economically with a nondeclining environmental quality over time. Environmental sustainability that embodies environmental quality, or rather the avoidance of the degradation of it, is measured in the form of environmental impacts such as climate change, acidification, eutrophication, fossil fuel energy use, resource depletion, smog, ozone layer depletion, and different forms of toxicity. The level of impact should be capped within the city's allocated share based on what is required for achieving global net minimum sustainability threshold. Economic progress as a proxy to economic sustainability in a city in this case is measured as increase in GDP per capita together with very low or decrease in GINI coefficient implies. The economic progress should be at the level where the city continues to make an operational profit that enables it to sustain its activities indefinitely. Social sustainability is represented by different aspects of social well-being such as inclusiveness, participation, employment opportunities, education successes, and health service coverage. It can be monitored by higher level of measured resident's satisfaction with sustaining their social well-being at the time of measurement and in the long run.

The rest of the chapter continues with a brief outline of challenges in cities, presentation of some life cycle opportunities, discussion of areas to be considered in achieving a life cycle sustainability of cities, and ending with the way forward.

2. Urban challenges

Cities operate in a resource-constrained platform that is full of challenges as they work with land use and planning priorities. Among the different ways to structure the challenges of cities, one conventional approach is to categorize issues by type of city department responsible for addressing them. Thermodynamically, challenges in our cities can be linked to the quantity and quality of material and energy generated and/or consumed in cities. These material and energy flows affect land use in and beyond the city boundaries. Creating a sustainable city is ensuring how it deals with its material and energy flows and how its physical assets are developed and managed from a life cycle perspective. It is about realizing ways of developing and managing sustainable buildings, water supply, waste management, wastewater treatment, and transport systems. It is about how a city serves its residents and how its economy is managed. The challenges are presented here in terms of material and energy flows entering, occurring, and leaving cities.

2.1. Material aspects of cities

The material dimension of cities includes the buildings, the infrastructure, green spaces and parks, and the transport. Under infrastructure, roads, city rails, water infrastructure, and wastewater infrastructure are covered. It covers both bound materials and material flows through cities. From concrete to steel, huge amounts of materials reside in and pass through mega cities [27]. The amount and type of materials in the building and infrastructures has been accumulating without meaningful thought concerning their fate. Traditionally, there were no regulatory requirements or economic or other forms of incentives to force or encourage material specifiers, builders, etc. to account for the end of life of the construction materials after the service life of the building or infrastructure is over. The toxicity buildup in these materials is worrisome, should the emitted substances make their way to our surface and groundwater or to the atmosphere.

When human beings used materials to build in the early days of urbanization in Asia and Africa, the materials were dominantly monotype and were loosely connected. Biomass in the form of straw, wooden beams and lintels, sun-dried clay mud, and stones consisted of most of these building materials. The materials, if necessary, could be disconnected easily and reused more than once. These materials were also harvested and collected from the immediate environment locally. With the advent of synthesis chemistry and the introduction of composite materials, the complexity of construction materials has increased significantly. The subsequent construction technologies of meshing up different types of materials have led to inseparable end products that can no longer be reused in a second life. The distances from which materials are sourced have also increased significantly for most of the supplies.

What we do in cities today will be critical in terms of influencing the material content of the existing building and infrastructure stock, which will stay for the next 50 years or more depending on the life time of the building and infrastructure. In the past and still in most cases, majority of these materials after demolition are sent to landfills. For lack of space and not-in-my-backyard pushes from local communities, cities are finding it difficult to get land-filling spaces to cope with the increasing quantity of building and demolition waste.

Regulatory restrictions and increasing awareness will force municipal decision-makers and developers to find new ways of sourcing new materials and using them in new constructions. Construction technologies need to account for the eventual disassembly of materials used in buildings and infrastructures and separation by material type.

Our knowledge of what materials contain and how they should be connected and used in buildings and infrastructure systems should account for how they will be disposed of at a later stage. Cities can save on extraction of virgin raw material and avoid other resources consumed during the extraction, processing, and transport of materials.

2.2. Water and wastewater aspects of cities

Many urban areas around the world do not provide basic services of clean water supply and adequate sanitation. In 2015, 2.1 billion people lacked access to safely managed drinking water [28]. Waterborne diseases are responsible for a significant number of deaths and lost productivity and shortened life expectancy in many developing countries. Almost 1000 days die of waterborne diseases associated with lack of appropriate sanitation and clean water before celebrating their fifth birthday [28].

Cities have been from the very beginning on a wasteful trajectory when it comes to water supply and treatment. One aspect of this resource leakage is that our urban areas continue to utilize potable water treated through a series of technologies and consuming energy and chemicals for treatment only to be used to flush toilets. We are so locked-in to this obsolete system that our plumbing education and building codes are tied to this unduly common and old inefficient practice. The dependence on these paths and system has prevented decentralized innovative solutions from making important contributions both in incremental and transformative changes of how water and wastewater services are delivered in cities. The solutions that are proposed to areas where there are poor and no such services at all are often large and centralized systems. Due to increased urbanization, many cities are overstretched in terms of water and wastewater treatment plant capacity. Building new systems and upgrading these large systems require big investments. The amount of energy consumed in the treatment of water and wastewater and the transport and distribution is one hindrance in operating and maintaining existing systems in cities where topography is challenging. Nutrient leakage associated with wastewater management is another aspect that needs attention.

2.3. Solid waste aspects of cities

The solid waste problem has economic implications in many developed cities. In developing countries, the issue takes a multifaceted form as it affects the social, environmental, and short-term and long-term economic advancements of urban areas. With increasing urbanization, the composition and quantity of waste is surpassing the already meager resource allocated to proper management of the waste in many cities of the developing world. According to the UN, the share of the world's population living in cities is expected to rise from 54 percent in 2014 to around 66 percent in 2050 [29].

The rate of increase of volume of solid waste generation is higher than the rate of urbanization as established by a World Bank report from 2012 [30]. By 2025, the planet will have 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste, that is, 2.2 billion tons per year. This increase in solid waste, which is the single largest budget item in many municipalities, will create unprecedented stress in cities in many developing countries, which are already operating under capacity in properly managing their solid waste. If current trends continue, a badly needed global "peak waste" will not happen this century [31].

2.4. Energy aspects of city buildings and transport

The heating, electricity, and fuel consumption of cities dominates the overall consumption of energy by society. Cities in the cold climate zones of the world specifically account for higher consumption of heat. The hottest regions of the world consume significantly high amounts of ventilation and air-conditioning energy. Decisions about the type and quantity of fuels used to deliver the relevant energy services often revolve around their energy intensity and impact intensity. Cities in different countries therefore have legislated to limit the amount of energy consumed by buildings. There has also been an increasing tendency of moving away from fossil fuel consumption in heating and electricity generation. Those in the cold climate regions will have to plan how their buildings and infrastructure will be heated during the long winter months of the year. The long-life time of buildings and the associated lock-in effect of the existing building stock require innovative approaches to redevelopment and urban renewable plans.

As the power grid decarbonizes, many cities in the world will continue to deal with their transport fuel. The amount of fossil fuel consumed for transportation in cities across the world is still the dominant contributor in both energy consumption and associated emissions of different types. This can be attributed to the high-carbon fuels and the increased mobility and expanding urbanization-led infrastructure systems. The expansion of these systems contributes to increase in indirect consumptions of energy through increased economic activities triggered by the infrastructures.

Measures aiming at energy efficiencies may not necessarily lead to the desired outcome of net reduction of energy and associated impact at the society level because of a potential rebound effect. Any extra money associated with energy efficiency when spent on previously nonexistent activity comes with higher energy consumption such as long-distance leisure travel; any gain from the energy efficiency is offset by the new energy-intensive activity and undermines the otherwise positive energy efficiency program.

Legislative and incentive instruments aiming at reducing energy use in cities with focus on buildings and transport systems better take a bigger picture and look beyond the different subsystems and factors including technological, architectural, urban form, lifestyle, behavioral, and cultural aspects (e.g., [32]).

3. Life cycle-based solutions for sustainable cities

Many of the problems that are established as critical in the context of urban areas are characterized as severe based on partial considerations of the full life cycle. They can be worse when accounted in their totality from a life cycle systems' perspective considering the downstream and upstream systems as well. Cities at the same time have a capacity of leverage in moving society at large in the right direction. Dematerialization of the urban infrastructure, exploring the area of integrated infrastructure and life cycle-based performance labeling are discussed as important elements of such opportunities. Capitalizing on such opportunities, however, demands a paradigm shift in the way cities do business.

3.1. Dematerialization of urban infrastructure

Innovative designs can be sought to reduce the quantity of materials extracted, processed, and utilized without compromising the quality of the infrastructure. This reduction in the amount of materials is not limited to what is finally bounded in the urban form. A life cycle perspective provides the opportunity to take stock of the materials that are wasted upstream in the mining and quarry sites as well as the waste that should have been diverted from landfills in and around cities. The life cycle lens goes beyond the embodied material during the preuse construction phase. Services provided by and on urban infrastructure should also be dematerialized. Dematerialization is better seen as covering both a relative and absolute decoupling of resource consumption and associated environmental impact from economic growth. It is realized through concerted efforts of achieving significant increase in material and environmental efficiency. At the broadest level, urban areas around the world should be developed and operated with an additional type of decoupling in mind that decouples human well-being from economic growth and consumption through a set of measures that include reduction of excessive consumption levels. Decarbonization as a specific case of dematerialization is best applied in the form of decarbonizing the energy and transport systems, which are the top two contributors for greenhouse gases in cities around the world.

3.2. Assessment integration and integrated infrastructure

Given existing building and infrastructure stock are here to stay for long, innovative technical and financial mechanisms are required to reuse old infrastructure systems and as last resort recycle materials from them. Repurposing should be a prioritized norm in renewal and redevelopment works of urban centers across the world. The task of repurposing will be increasingly huge with game-changing technical transformation globally. One good example is the large-scale introduction of autonomous vehicles. The need for our massive parking surface and above surface structures will be reduced significantly, and large part of these structures will be abandoned. It is, thus, time to rethink new purposes for them and redesign and redevelop them for a second life and beyond. New projects can be designed and implemented using advanced knowledge using our experience and by finding synergies between different urban forms. Best practices around the world should be emulated with focused attention to local contexts and variables. Urban decision-makers will benefit from twofold integration in relation to infrastructure systems in cities: integration of assessment aspects and integration potentials of infrastructure systems.

Under the assessment integration, elaborating the concept of a comprehensive integrated assessment in relation to decision analysis of infrastructure development and management is important. Setting higher environmental, social, and economic standard on our cities requires the integration of decision-making related to urban infrastructure systems by looking at the triple bottom line as a more comprehensive platform for complementary consideration of the most important and relevant variables while avoiding double counting of the aspects informed by such variables. Understanding the sustainability (environmental, social, and economic) performance of current best practices of developing and managing the totality of urban infrastructure systems and how future technical and nontechnical changes influence the sustainability is crucial. Conventional practices focus either on only one aspect of the sustainability or on only one infrastructure at a time and/or only part of the life cycle of the infrastructure. Decisions based on such partial information and circumscribed knowledge should be replaced by more complete knowledge as an input to the decision analysis stage of the development and management of future infrastructure systems. A comprehensive account of relevant environmental, social, and economic aspects of our urban infrastructure provides municipalities and higher level of governments the opportunity to look at the opportunities, the synergies, and trade-offs associated with alternative development and operational decisions. Our understanding of the performance of the current best practices of developing and managing infrastructure systems from environmental, social, and economic perspective is weak. Even weaker is the level of knowledge we have around the changes in performance in the future with the introduction of technical and nontechnical shifts that can potentially happen in the next 10–30 years. Without an actionable knowledge regarding the current and future potential performance of our cities, we will fall short of getting it right in terms of what measures will be critical in containing the negative impacts of disruptions that affect infrastructure systems from a life cycle perspective. Integrated assessment provides the opportunity of identifying cobenefits and adverse side effects, which will otherwise lie outside conventional assessment lens (see, e.g., [32]).

On integrated infrastructure, exploring how different levels and scales of physical integration, data integration, resource integration, management integration, and other forms of integration affects the overall performance of infrastructure systems is critical. In some cities, there is

http://dx.doi.org/10.5772/intechopen.81633

already a demonstration of integration of infrastructure systems through connecting material and energy flows of individual systems [33]. Connecting the waste management infrastructure with the transport system using fuels such as biogas produced from waste to power vehicles is one example. Or the use of waste-driven electricity to power transport systems could link the three infrastructure systems through material and energy flows. Advanced integration will be physical (e.g., surface) integration. The future which in many areas is already here holds promising technologies in terms of integrated infrastructure such as solar shingles and solar panel roads. The photovoltaic layered roads or pedestrian ways, for example, can increase the values of infrastructure by adding new functions or layering functions, which is the basis of life cycle assessment's focus on functions of product systems. Envisioning new vehicle technologies that can charge while driving wireless/wire free from the roads and even from other autonomously driven vehicles is not wild. These kinds of developments will, of course, require all kinds of new fiscal, regulatory, and social transformation to work effectively.

3.3. Life cycle-based labeling and certification

As cities and nations increasingly set greenhouse gases-focused goals and broader sustainability targets, there is a need for measuring, monitoring, and communicating performances and progresses made. Increased sustainability awareness of citizens and the demand for better options offered by cities and parts of cities to prospective residents would encourage the development of sustainability rated or certified infrastructures, districts, neighborhoods, and cities in the future. Assessments that can potentially support such ratings and certifications come in different shapes and sizes depending on the purpose, scope, and object of assessment. Life cycle assessment is about evaluating the environmental impacts of product systems such as buildings and infrastructure systems over their life cycle. Environmental impacts covered in a comprehensive life cycle assessment include climate change, ozone layer depletion, smog, eutrophication, acidification, human toxicity, ecotoxicity, biotic resource depletion, abiotic resource depletion, and fossil fuel depletion. Life cycle sustainability builds on life cycle assessment to include life cycle costing and social life cycle assessment.

Metrics for monitoring and communicating supported by quantitative data are helpful. There is, however, a need for scrutinizing the quality of data, for example, by qualifying the assessment results and conclusions. More and better data collection from primary sources will be useful in addressing the kind of uncertainty associated with, for example, urban greenhouse gases inventory [34].

Verifiable and independently reviewed sustainability labeling and certification of buildings, neighborhoods, infrastructure systems, subcities, and cities has the potential of sending the right signals to the market and thereby fostering the expansion of best practices and state-of-the-art design, development, and management of the different levels of organization of our urban areas. The performance labeling of infrastructure systems and other elements of urban forms will benefit from the experience of working with the life cycle-based environmental product declarations (EPDs) in the building sector. Rules that set the principles and requirements to be followed in developing EPDs are set in product category rules (PCRs) established through deliberative and participatory processes involving different stakeholders including relevant industrial associations. Both PCRs and EPDs as a basis for verification, comparison, and evidence-based monitoring are developed as living documents and are updated from time to time to capture new data and knowledge, new technology, and new requirements.

4. Toward life cycle sustainability of cities

Urban sustainability is both about how to make new developments sustainable while renewing existing building and infrastructure stock to fit the sustainability requirements of future cities. Urban areas of the future will be dominated by self-driving vehicles, renewable powered homes, and artificial intelligence-enabled systems and service. They will be better defined by how much of their physical assets and material flows in cities are in line with the principles of circular economy. Cities are well positioned to catalyze the institutional and technical aspects of rolling out a well-thought strategy for realizing an urban circular economy that covers physical assets in the city, products and services that are produced and/or consumed or pass through it. Circular economy is about ensuring a full account of the design, production, distribution, use, reuse/repair, and recycling with few net inputs of raw materials. Many cities around the world are at the bottom of the pyramid of hierarchy of material efficiency broadly known as "reduce, reuse, recycle, recover, and dispose," which is at the core of the circular economy as materials and consumables are still disposed in open dumps in many developing countries.

Three areas of interest will drive the path to the development of more sustainable cities: triple bottom line space of better sustainability conditions; life cycle data access and quality; and streamlined semiquantitative life cycle evaluations.

4.1. Triple bottom line space of better sustainability conditions

Decision-makers at different levels struggle on regular basis with multitude of trade-offs. They are better supported by tools and frameworks that show beyond impact assessment results. A decision-maker wants to know as to what makes a given alternative better or the best of the pool and what elements should be in place to make the selected alternative work. For new technologies, designs, and development proposal, the need for such appraisal is more critical.

The concept of triple bottom line space of better sustainability conditions is here introduced as a suit of social, economic, and environmental conditions that a development proposal or a redevelopment plan of an existing part of a city should meet to function based on life cycle sustainability principles. The concept refers to a performance space delimited by the boundaries and thresholds of environmental, economic, and social conditions that can potentially encourage implementation of new ideas, new technologies, and novel solutions in urban areas around the world. These boundaries can be set based on context-specific analysis that leads to city-wide net sustainability. The premise is that urban development options and pathways with triple bottom line performance numbers within the boundary conditions have higher chance of broader management and public buy-ins than those that lie outside the space boundary conditions. Research is required on how to establish the lower and upper boundaries of space in view of creating the triple bottom line feasibility considering policy, market forces, and consumer perspectives.

Under social conditions are the sustainability-relevant behaviors of residents and barriers associated with product-related and lifestyle and culture-oriented practices. These include behaviors that lead to decrease or increase in energy and water consumption, recycling and composting waste, and supporting wildlife in gardens; travel behavior and car ownership; social participation; and the use of local services, businesses, and facilities [9]. Under economic conditions are city activities that lead to a per capita income level that allows a sustainable level of consumption and a rate of job creation that agrees with the rate of increase in labor force. The environmental conditions allude to a requirement that relevant per capita, per dollar, and per spatial area impact metrics are within a globally threshold that does not undermine the sustainability of human life. One relevant global threshold, for example, is an annual per capita greenhouse gases emissions limit calculated globally as the maximum threshold to avoid unprecedented disasters due to climate change.

Life cycle sustainability assessment can be used to conduct baseline analysis, for example, on the natural resource extraction, energy, and impact intensity of materials and energy use in the current best practice of construction, operation, and decommissioning of infrastructure systems and other physical elements that affect the urban form in different ways. It can also be used to appraise future changes focusing on the life cycle performance of technical and nontechnical changes that affect the amount and type of material and energy utilization at the different stages of the life cycle of the urban infrastructure system. The appraisal process should be informed by social and economic criteria embedded in screening and prioritization tools. Integrated life cycle sustainability assessment covering the social feasibility, economic feasibility, and environmental feasibility serves as a basis for ensuring better political feasibility in city councils around the world.

4.2. Life cycle data access and quality

The future of our cities can be better shaped by more data-driven and evidence-based participatory decision-making. The three tools that make up the life cycle sustainability assessment framework are data intensive. The critical challenges of conducting the assessment are, thus, related to access to quality data. This problem gets more serious when we account for different scenarios of future technical and nontechnical changes and try to model them. Fulfilling the data requirements involves data collection, database development, and interfacing with existing data sources. We are in an era where huge amount of data resides and continues to pile up in the public and corporate realm. Data mining, access to relevant data, and presenting the data in a digestible format are part of the challenge. In the context of life cycle sustainability assessment, data sources include primary sources from cities and secondary data sources from literature such as peer-reviewed publications, reports, and generic life cycle databases. For environmental life cycle data, commercial databases are increasing available. For example, the Swiss Ecoinvent life cycle database [35] covers many product systems including energy systems in many parts of the world and other infrastructure-related datasets. Commercial databases can be purchased as part of commercial life cycle assessment software tools or as standalone databases. Free public alternative sources of life cycle data are still under development. One such example is the US Life Cycle Inventory database [36]. For social life cycle data, Social Hotspots Database (SHDB) [37] and Product Social Impact Life Cycle Assessment (PSILCA) [38] are the two available currently. For life cycle costing, generic data on material, labor, and equipment can be found from the RSMeans database [39].

4.3. Streamlined semiquantitative life cycle evaluation

Not all cities interested in sustainability issues are necessarily capable of conducting quantitative life cycle sustainability assessment. Nor is it necessary to resort to detailed quantitative assessment all the time in all contexts. There are many decision situations that only merit streamlined semiquantitative systems of accounting for all three dimensions from a life cycle perspective. The systems allow for quick assessments at a relatively low cost. They come with the capacity to capture aspects that are inherently nonquantitative. They also result in relatively easy-to-understand outcomes digestible to nonexperts. Such score-based system can take a form of a matrix structure composed of areas of protection or concern that represent the social, environment, and economic aspects on one side and the different life cycle stages on the other. The score values can be assigned based on a mix of experience, expert knowledge, previous studies, relevant checklists, and guidelines. Decision analysts working for municipalities can use such matrices or equivalent graphic systems to structure assessment information and results together with, for example, workshop-driven stakeholder perspectives in supporting decision-making.

Once relevant and critical aspects or physical assets of cities are identified using critical streamlined semiquantitative life cycle evaluation, the need for a demanding and detailed life cycle sustainability assessment that is based on quantitative environmental life cycle assessment and life cycle costing and quantitative and qualitative social life cycle assessment can be explored depending on the utility of the potential results to the decision context and resource availability.

5. The way forward

In pulling our cities out of institutional and infrastructural lock-ins and suboptimized planning and operational setting, three areas of need are identified: need for best practice demonstrations; need for framework for global urban sustainability; and need for life cycle sustainability literacy.

5.1. Best practice demonstrations

Measurable goals supported by multidimensional aspects and associated indicators are crucial in informing the planning, development, and rehabilitation projects in urban areas. The adaptation of indicators used in existing rating systems such as LEED Neighborhood and BREAM Communities to city scale is recommended [23]. Moreover, planners and developers benefit from real-world demonstration of good practices of the process and products of (re) development of districts and cities around the world.

Two city district-level cases that can be emulated by other cities customizing to local variables are Hammarby Sjöstad and Royal Seaport in Stockholm. Hammarby Sjöstad was designed in the early 1990s and developed on an old industrial area of 150 ha (200 ha with water) over the period of 12 years since 2004. Once completed, there will be 11, 000 apartments and around 35,000 people in the district [40]. It all started with an ambitious goal of becoming "twice as good" compared to the state-of-art of construction sector of the time. The detail of this goal was part of an environmental program that was adopted by the City Council of Stockholm and handed to developers. It included specific quantitative goals such as total supplied energy per square meter not exceeding 60 kWh with electricity capped at 20 kWh. It was also mentioned that the district will be built in line with the principles of natural cycles. To close the material and energy cycle locally, the Hammarby Model was later developed where solid waste and wastewater from the district are recovered in the form of electricity, transport fuel, heating, and cooking energy for use in the district [41]. The Hammarby Model captures how different systems in the district are integrated [41].

In a detailed evaluation of Hammarby Sjöstad, it was assessed as successful overall [42]. The closing of cycles has led to the reduction in metabolic flows though it is far from making the district energy wise self-sufficient [33]. The evaluation provided some recommendations for use in future (re)development projects. One such recommendation focuses on the need for integrating environmental goals early in the planning process. In Hammarby Sjöstad, the environmental program came 4 years after planning activities started. A second recommendation captured the importance of accounting for behavioral aspects of future district residents and technological limitation as part of the same holistic vision. There have recently been concerns raised by the residents of the district regarding the significant increase in the number of young people in the area, which was more than what was accounted for in the planning and development process. One aspect of the concern is the absence of a natural meeting place for the young residents within the district limits. The need to incentivize residents to live more sustainably in addition to the technical operational improvements built as part of the physical elements of the district is stressed [42].

Building on experience of Hammarby Sjöstad, a second more ambitious project on another sit in the north-east of Stockholm is under development. The Norra Djurgårdsstaden or in English the Royal Seaport started in 2009 and is right now Europe's most comprehensive urban development project pursuing the goal of creating an environmentally friendly district with at least 12,000 apartments and 35,000 residents [43]. It aims to become a fossil fuel-free district by 2030 by deploying renewable energy. Its near-term goal is limiting its per capita emission of carbon dioxide to 1.5 ton. A closed cycle model where linkages and synergies will be highlighted is also part of the plan. Developers of Royal Seaport project agreed to a legally binding building energy performance target of 55 kWh/m^2 [43]. The literature is full of connecting the concepts of smart city and sustainable city in projects like the Royal Seaport [44–46]. The political support for the Hammarby Sjöstad by Stockholm City Council was repeated for Royal Seaport by approving the environmental and sustainability program for the project in October 2010 [47]. The environmental, social, and economic sustainability goals of the district are to be realized through eight focus areas targeting technical and behavioral aspects. These are environmentally adapted residential and commercial premises; sustainable energy systems; sustainable water and wastewater systems; sustainable transport; sustainable recovery systems; climate-adapted and green outdoor environment; sustainable lifestyles; and sustainable businesses [47].

Other discussions on examples from North America include the city of Portland's Pearl District [48, 49] and Minnesota's Winona [50].

5.2. Framework for global sustainability of cities

As no city can be truly sustainable in isolation, a set of targets and indicators (e.g., [51]) to be adopted by all cities around the world is necessary. Despite its limited ambition, the UN Sustainable Development Goals (SDGs) adopted in 2015 with 2030 targets for all countries offer such a global framework that covers cities across the world. Of the 17 SDGs, SDG 11 on Sustainable Cities and Communities has most direct connection to cities. However, other goals such as SDG 3 on Good Health and Well-being; SDG 5 on Gender Equality, SDG 6 on Clean Water and Sanitation; SDG 7 on Affordable and Clean Energy; SDG 8 on Decent Work and Economic Growth; SDG 9 on Industry, Innovation and Infrastructure, and SDG 10 on Reduced Inequality are all relevant to how we develop and manage our urban areas. The same with the SDG dedicated for dealing with climate change. In a work on the network and integrated feature of SDGs, SDG 11 is presented as connected to six other SDGs [52]. Direct and indirect connections can also be made between the SDGs and the material, energy, and water flows to and from urban areas.

SDG 11 has 10 targets and 15 indicators that together recognize housing (sustainable resilient and resource-efficient buildings), basic services, waste management, transport, and public spaces as physical assets of cities. It considers natural and cultural heritage, global GDP, life and health of people as safeguard objects. A close examination of this SDG unravels implicit and explicit performance attributes of a sustainable city such as adaptation to climate change; adequacy; affordability; accessibility; convenience; free of physical and sexual harassment; holistic approach; inclusion; increase in land use efficiency (low land use rate to population growth rate ratio); integration; mitigation of climate change; participation; protection of poor and people in vulnerable situations; reduction in disaster risks; reduction in disaster-driven deaths; reduction in number of people affected by disasters; reduction in adverse per capita environmental impacts such as fine particulate matter; resource efficiency; resilience to disasters; safety; substantial decrease of economic loss; and support for positive, economic, social, and environmental link within and to surrounding areas of urban centers. SDG 11 envisions a sustainable city that avoids disasters that damage critical infrastructure and disrupt basic services.

Cities achieve these performance attributes through integrated policies and plans at urban, regional, and national levels; urban management; risk management; and local and national disaster risk reduction strategies. Environmental issues explicitly mentioned in SDG 11 are climate change, waste, air pollution, and particulate matter. This SDG mentions sustainable, resilient, and resource-efficient building and use of local building materials only and specifically in the context of least developed countries. It is not clear why the buildings of developed countries that were designed, constructed, and operated inefficiently and unsustainably are not included.

5.3. Life cycle sustainability literacy

Sustainable urban development's accounting for circumstances of constrained resources under which they occur needs to be undertaken in ways that avoid or minimize lock-in and rebound effects. Informed decisions regarding different elements of the urban fabric should be made with the goal of creating cascading positive impacts. For example, accessible golf courts that are organically integrated within the network of built-up areas of cities serve environmental functions on top of the social well-being, associated with recreation and active life as their accessibility and affordability, potentially lead to a reduction of long-distance leisure travels by local golfers and avoids or reduces impacts attributed to hotel and other related activities.

Life cycle sustainability consideration of all relevant aspects for creating new cities and redeveloping the existing comes with the complexity of working with "complementarities and contradictions within the dimensions of urban sustainability" [9]. To this end, life cycle sustainability literacy at technical and managerial level of cities is required on, for example, the material and energy ramifications of decisions passed by city council on upstream and downstream systems.

At the technical level, the capacity building task should cover on how to work with better data and state-of-the-art methodology.

At the managerial level, there is a need for understanding that life cycle sustainability assessment offers systemic view that recognizes the indivisibility of systems and sustainability even when looking at the subsystems and the individual dimensions before bringing everything into one whole.

A platform that seeks to address inequality and climate change in cities called Future Cities Canada identified areas to work on such as evaluation and impact indicators, needs-driven data, and evidence-based decision-making [53]. All these areas can be mapped into environmental and social bottom line of life cycle sustainability to be developed as part of a literacy kit for urban decision-makers.

Evidence-based decision-making at the decision-makers' and city residents' level has the potential to push cities on a sustainable development trajectory toward better sustainability. Life cycle perspective of such evidence-driven intervention recognizes long-term and lasting impacts of current decisions requiring continued commitment. Our urban world and our planet at large benefits from a depoliticized use of the life cycle view as a golden thread of planning and development. It provides a platform for engaging stakeholders along the life cycle irrespective of ideological orientation. That will potentially drive meaningful and long-lasting changes that leverage on a broader acceptance across the political spectrum.

Capacity building and awareness raising efforts will be effective if they start on streamlined semiquantitative life cycle sustainability assessment without resorting to detailed quantitative assessment.

6. Conclusions

The material and energy flow perspective of diagnosing our cities and setting goals of transforming them into more sustainable forms captures the essence of many of the global and local environmental challenges we face while it provides insights about the economic and social sustainability of what we do with the material and energy. The dominant and narrow notion of less-is-better falls short of optimal solutions as it cultivates different levels of burden shifting and suboptimization. Conventional analysis and the actions it derives only move the problem of one environmental medium into a problem of different medium. Cities have been pushing contemporary waste problems into future problems by, for example, landfilling divertible wastes. Plastic wastes from our cities and other parts of the economy have been shipped to China for so many years to the extent that it has assumed as a nonissue locally until this year when China banned the import of plastic waste from other countries including Europe and North America. The practice has been shifting the problem geographically. When the world successfully phased of chemicals that depleted the ozone layer, some of the replacements were later found to be highly potent greenhouse gases. Solving the ozone layer depletion problem was followed by unwelcome development of negatively impacting another global problem.

The consequences of the suboptimal vicious circle of solving one problem by creating another problem or parking problems for tomorrow or pushing issues spatially can be avoided at best or reduced at least by having enough level of life cycle literacy that can inform the public-level and corporate-level decisions that seek to replace old systems with new alternatives. Moving toward a thorough and comprehensive consideration of the important parts of the life cycle of material and energy used in cities, all the environmental, social, and economic aspects associated with that use within a well-defined temporal and spatial system boundary are important. Retraining current cohorts of technical and managerial staff of our cities and educating new generation of decision-makers with the skill of crafting life cycle goals and communicating to relevant stakeholders will energize such full systems-level accounting.

It is not practical or necessary to have a detailed quantitative calculation for every part of the material and energy aspects of our urban areas. Continuing with a piecemeal approach that in the long run and from a broader perspective is not cost-effective, and a disservice to the people, the planet and broad-based profit is not an option.

Author details

Getachew Assefa

Address all correspondence to: gassefa@ucalgary.ca

University of Calgary, Alberta, Canada

References

[1] Ziari K, Pourahmad A, Fotouhi Mehrabani B, Hosseini A. Environmental sustainability in cities by biophilic city approach: A case study of Tehran. International Journal of Urban Sciences. 2018:1-31. DOI: 10.1080/12265934.2018.1425153

[2] Nikulina V, Baumann H, Simon D, Sprei F. Sustainable transport futures: Analysis of the selected methodologies supporting the planning process towards achieving goal 11 sustainable cities and communities. In: Handbook of Sustainability Science and Research. Cham: Springer; 2018. pp. 473-488

[3] Hammond GP, Jones CI. Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers—Energy. 2008;**161**(2):87-98

[4] Parkin S, Sommer F, Uren S. Sustainable development: Understanding the concept and practical challenge. Proceedings of the Institution of Civil Engineers—Engineering Sustainability. 2003;**156**(1):19-26

[5] Banister D, Watson S, Wood C. Sustainable cities: Transport, energy, and urban form. Environment and Planning B: Planning and Design. 1997;**24**(1):125-143

[6] Satterthwaite D. Sustainable cities or cities that contribute to sustainable development. Urban Studies. 1997;**34**(10):1667-1691

[7] Moffatt I. Edinburgh: A sustainable city? International Journal of Sustainable Development and World Ecology. 1999;**6**(2):135-148

[8] Korhonen J, Honkasalo A, Seppälä J. Circular economy: The concept and its limitations. Ecological Economics. 2018;**143**:37-46

[9] Jenks M, Jones C. Dimensions of the Sustainable City. Vol. 2. Future City, Dordrecht: Springer Netherlands; 2010

[10] Dempsey N, Brown C, Bramley G. The key to sustainable urban development in UK cities? The influence of density on social sustainability. Progress in Planning. 2012;**77**(3): 89-141

[11] Hillman T, Janson BN, Ramaswami A. Spatial allocation of transportation greenhouse gas emissions at the city scale. Journal of Transportation Engineering—ASCE. 2011;**137**(6):416-425

[12] Dodman D. Forces driving urban greenhouse gas emissions. Current Opinion in Environmental Sustainability. 2011;**3**(3):121-125

[13] Newton P. Liveable and sustainable? Socio-technical challenges for twenty-first-century cities. Journal of Urban Technology. 2012;**19**(1):81-102

[14] Jim C. Sustainable urban greening strategies for compact cities in developing and developed economies. Urban Ecosystems. 2013;**16**(4):741-761

[15] Azizalrahman H, Hasyimi V. Towards a generic multi-criteria evaluation model for low carbon cities. Sustainable Cities and Society. 2018;**39**:275-282

[16] Liqun L, Chunxia L, Yun-guang G. Green and sustainable city will become the development objective of China's low carbon city in future. Iranian Journal of Environmental Health Science & Engineering. 2014;**12**(1):34-34

[17] Bulkeley H, Betsill M. Rethinking sustainable cities: Multilevel governance and the 'urban' politics of climate change. Environmental Politics. 2005;**14**(1):42-63

[18] Hendricks MD, Meyer MA, Gharaibeh NG, Van Zandt S, Masterson J, Cooper JT, et al. The development of a participatory assessment technique for infrastructure: Neighborhood-level monitoring towards sustainable infrastructure systems. Sustainable Cities and Society. 2018;**38**:265-274

[19] Rodrigues JPC. Local government aimed at quality of life in sustainable cities. In: Entrepreneurial, Innovative and Sustainable Ecosystems. Cham: Springer; 2018. pp. 35-53

[20] Hassan AM, Lee H. The paradox of the sustainable city: Definitions and examples. Environment, Development and Sustainability. 2015;**17**(6):1267-1285

[21] Girardet H. Creating Sustainable Cities. Vol. 2. Devon, England: Resurgence Books; 1999

[22] Rauscher RC. Directions for planning sustainable cities and neighborhoods. In: New York Neighborhoods—Addressing Sustainable City Principles. Cham: Springer; 2018. pp. 217-232

[23] Barbosa JA, Bragança L, Mateus R. New approach addressing sustainability in urban areas using sustainable city models. International Journal of Sustainable Building Technology and Urban Development. 2014;**5**(4):1-9

[24] Foliente G, Kearns A, Maheepala S, Bai X, Barnett G. Beyond triple bottom line—Sustainable cities RD&D at CSIRO. 2007

[25] Dassen T, Kunseler E, Kessenich LM. The sustainable city: An analytical-deliberative approach to assess policy in the context of sustainable urban development. Sustainable Development. 2013;**21**(3):193-205

[26] Williams K. Sustainable cities: Research and practice challenges. International Journal of Urban Sustainable Development. 2010;**1**:128-132

[27] Kennedy CA, Stewart I, Facchini A, Cersosimo I, Mele R, Chen B, et al. Energy and material flows of megacities. Proceedings of the National Academy of Sciences. 2015; **112**(19):5985-5990

[28] UN. Water, Sanitation and Hygiene. Available from: http://www.unwater.org/water-facts/water-sanitation-and-hygiene. [Accessed: October 28, 2018]

[29] United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). 2014. Available from: https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Highlights.pdf [Accessed: Dec 11, 2017]

[30] Hoornweg D, Bhada-Tata P. What a Waste: A Global Review of Solid Waste Management. Washington, D.C.: World Bank; 2012

[31] Hoornweg D, Bhada-Tata P, Kennedy C. Environment: Waste production must peak this century. Nature News. 2013;**502**(7473):615

[32] IPCC. Climate change 2014: Mitigation of climate change. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, et al., editors. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom, and New York, NY, USA: Cambridge University Press; 2014

[33] Iveroth SP, Johansson S, Brandt N. The potential of the infrastructural system of Hammarby Sjöstad in Stockholm, Sweden. Energy Policy. 2013;**59**:716-726

[34] Wattenbach M, Redweik R, Lüdtke S, Kuster B, Ross L, Barker A, et al. Uncertainties in city greenhouse gas inventories. Energy Procedia. 2015;**76**:388-397

[35] Wernet G, Bauer C, Steubing B, Reinhard J, Moreno-Ruiz E, Weidema B. The ecoinvent database version 3 (part I): Overview and methodology. The International Journal of Life Cycle Assessment. 2016;**21**(9):1218-1230. Available from: http://link.springer.com/10.1007/s11367-016-1087-8 [Accessed: Aug 31, 2018]

[36] U.S. Life Cycle Inventory Database. National Renewable Energy Laboratory, 2012. 2018. Available from: https://www.lcacommons.gov/nrel/search [Accessed: Aug 31, 2018]

[37] Norris CB, Norris G, Aulisio D. Social Hotspots Database. 2013. Available from: http://socialhotspot.org

[38] Ciroth A, Eisfeldt F. PSILCA—A Product Social Impact Life Cycle Assessment Database. Database Version 1.0. Berlin: GreenDelta GmbH; 2016

[39] Waier PR, Babbitt C, Baker T, Balboni B, Bastoni RA. Rockland, Massachusetts: RSMeans, Building Construction Cost Data. 2018

[40] Iverot SP, Brandt N. The development of a sustainable urban district in Hammarby Sjöstad, Stockholm, Sweden? Environment, Development and Sustainability. 2011;**13**(6):1043-1064

[41] Iveroth SP, Vernay AL, Mulder KF, Brandt N. Implications of systems integration at the urban level: The case of Hammarby Sjöstad, Stockholm. Journal of Cleaner Production. 2013;**48**:220-231

[42] Pandis S, Brandt N. Utvärdering av Hammarby Sjöstads miljöprofilering: vilka erfarenheter ska tas med till nya stadsutvecklingsprojekt i Stockholm? (Evaluation of the Hammarby Sjostad's Environmental Profile—What Experiences should be taken to new urban development projects in Stockholm?). In: Avdelningen för industriell ekologi. Stockholm: Kungliga Tekniska högskolan; 2009

[43] Shahrokni H, Årman L, Lazarevic D, Nilsson A, Brandt N. Implementing smart urban metabolism in the Stockholm Royal Seaport: Smart city SRS. Journal of Industrial Ecology. 2015;**19**(5):917-929

[44] Garau C, Pavan VM. Evaluating urban quality: Indicators and assessment tools for smart sustainable cities. Sustainability. 2018;**10**(3):575

[45] Ibrahim M, El-Zaart A, Adams C. Smart sustainable cities roadmap: Readiness for transformation towards urban sustainability. Sustainable Cities and Society. 2018;**37**:530-540

[46] Silva BN, Khan M, Han K. Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities. Sustainable Cities and Society. 2018;**38**:697-713

[47] Holmstedt L, Brandt N, Robèrt KH. Can Stockholm Royal Seaport be part of the puzzle towards global sustainability?—From local to global sustainability using the same set of criteria. Journal of Cleaner Production. 2017;**140**:72-80

[48] Hall AR. Scaling sustainable infrastructure: District design for the triple bottom line [University Honors theses]. Paper 621. Portland State University; 2018

[49] Ramiller AJ. From the Neighborhood Up!: Neighborhood Sustainability Certification Frameworks and the New Urban Politics of Scale. Geography Honors Projects. 56. Macalester College; 2018. Available form: http://digitalcommons.macalester.edu/geography_honors/56 [Accessed: Oct 28, 2018]

[50] Borsari B, Mundahl N, Morse A, Mutter P, Howard JW. Achieving sustainability in the city of Winona, Minnesota (USA): A case study. In: Lifelong Learning and Education in Healthy and Sustainable Cities. Cham: Springer; 2018. pp. 327-340

[51] Koch F, Ahmad S. How to measure progress towards an inclusive, safe, resilient and sustainable city? Reflections on applying the indicators of sustainable development goal 11 in Germany and India. In: Urban Transformations. Cham: Springer; 2018. pp. 77-90

[52] Le Blanc D. Towards integration at last? The sustainable development goals as a network of targets. Sustainable Development. 2015;**23**(3):176-187

[53] FCC. 2018. Available from: https://futurecitiescanada.ca/about [Accessed: Sep 21, 2018]