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Circular Cities: Challenges to Implementing Looping Actions

Joanna Williams

Bartlett School of Planning, University College London, London WC1H 0NN, UK; Joanna.williams@ucl.ac.uk

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Abstract: Currently cities consume 60–80% of natural resources globally. They produce 50% of global waste and 75% of green-house gas emissions. The UN estimates that 66% of the world's population will live in cities by 2050 while the global urban footprint will triple over the years to 2030. Thus cities, as a system of production and consumption, threaten the environmental sustainability of the globe. Looping actions—reuse, recycling and recovery of resources (materials, energy, water, land and infrastructure)—can help to address resource scarcity and wastage in cities. However, there are many challenges to implementation. Much of the literature explores the challenges to looping actions within resource sectors and for specific actions (i.e., challenges to adaptive reuse of buildings, recycling of material waste, energy recovery from sewage). It often does so without any clear reference to context. Nexus solutions are becoming a popular resource looping response to tackling wastage in cities. Some of the challenges to implementation have been explored, but influence of context has not been investigated. In this paper we explore the challenges facing the implementation of looping actions in cities. Using a mixed methods approach, we identify 58 challenges to looping actions across eight themes. We also establish the challenges to implementing a nexus solution. The research identifies five common implementation challenges. Addressing these challenges could enable looping actions across resource types in cities. The research also demonstrates how context affects the challenges to implementing looping actions and nexus solutions in cities. Nevertheless, the analysis suggests that there are some common levers for promoting looping actions and nexus solutions in cities, regardless of context.

Keywords: resource looping; circular economy; nexus: recycle; reuse and energy recovery; circular cities; resource management; urban sustainability

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1. Introduction

Currently cities consume 60–80% of natural resources globally. They produce 50% of global waste and 75% of green-house gas emissions [1]. The UN estimates that 66% of the world's population will live in cities by 2050 [2] while the global urban footprint will triple over the years to 2030 [3]. Adopting a circular approach to resource management in cities could help to address these problems. Looping actions—reuse, recycling and energy recovery—are integral to the delivery of circular resource flows in cities [4]. Yet there are many challenges to the implementation of these actions.

Cities are facing resource scarcity and security issues. The number of water-stressed cities is growing rapidly [5]. Cities remain reliant on fossil fuels, which makes them particularly vulnerable to hikes in fuel price and energy embargoes [6]. Looping actions could help to address water and energy scarcity in cities, for example through the reuse of grey-water [7,8] and recovery of energy from bio-waste and capturing waste heat from industry [9,10].

There are substantial accumulations of natural resources in buildings, infrastructure, products and waste deposits in cities. Disused urban infrastructure and "waste" materials can be reused or recycled for new purposes [11]. These technospheric resource reservoirs offer an opportunity for more sustainable development [12]. For example, reuse of construction materials can produce significant resource savings, a reduction in waste disposed in landfill and the energy required for the production of virgin materials [13]. Infrastructure can also be adaptively reused or repurposed to suit the changing needs of the urban population and to avoid redundancy in the system [14,15].

It is important that vacant land in the city is reused and brownfield sites are recycled. Land offers ecosystem services (supporting, provisioning, regulating and cultural services). Green space in cities can regulate climate, air, and water quality; enable nutrient and water cycling and soil formation; provide spaces for growing food and for recreation [9,15–17]. Equally space is needed for the infrastructure which enables resource recycling, reuse and recovery (e.g., grey-water reuse systems, eco-industrial parks, waste reprocessing plants). Often land is scarce in cities, thus it is important to reuse or recycle sites as they become available.

Much of the literature which explores the challenges to recycling, reuse and energy recovery does so within resource sectors and for specific actions (i.e., adaptive reuse of buildings, recycling of material waste, energy recovery from sewage). The common challenges across resource types and looping actions are not discussed. Nor has the effect of context on implementation challenges been explored. In this paper we add to current theoretical understanding by focusing on the common implementation challenges across looping actions and resource types within the city. We examine how context affects the challenges to implementation. We also investigate the challenges to implementing nexus-type solutions and how these alter with context. From this analysis we begin to understand the potential levers for promoting looping actions and nexus solutions in cities.

2. Methodology

A three-stage, mixed-methods approach was used. A literature review, expert workshop and comparative case studies were employed. This three-stage approach was adopted to increase the robustness of the findings and enable triangulation between results.

2.1. Literature Review and Inductive Analysis

An analysis of the literature was completed to determine the challenges to implementing looping actions in cities across resource types. Over 200 relevant documents (academic and technical) were reviewed across several disciplines (Economics (circular economy), management (resource, waste and construction management), engineering (civil and environmental), industrial and urban ecology, sustainability, urban studies, planning, urban geography). The search terms for identifying relevant papers investigating looping actions are listed (Table 1). The literature was analysed using inductive content analysis. The analysis identified eight over-arching themes and within those themes around 58 challenges. This produced a coding framework for the following analyses.

Table 1. Looping actions across resource types—search terms.

	Reuse	Recycle	Energy Recovery
Definition	Where resources are used again without any further processing	Where resources are reprocessed for the original or other purposes	Energy is produced from the reprocessing of resources
Materials	Reuse of goods and materials; primary and secondary recycling, exchange of goods and materials	Materials recycling, tertiary recycling, composting, landfill mining	Gasification, pyrolysis, landfill gas collection, anaerobic digestion, fermentation, refuse derived fuel combustion.
Infrastructure	Adaptive reuse, repurposing, change in use, refurbishment	Urban mining, infrastructure recycling	-
Water	-	Grey-water recycling/reuse. Waste-water reuse, recycled water, reclaimed water, sewage treatment	Drain water heat recovery, grey-water heat recovery, hot water heat recycling, biogas, thermal hydrolysis, anaerobic digestion

Table 1. *Cont.*

	Reuse	Recycle	Energy Recovery
Energy	-	-	Gasification, pyrolysis, landfill gas collection, anaerobic digestion, fermentation, refuse derived fuel combustion, drain water heat recovery, grey-water heat recovery, hot water heat recycling, biogas, thermal hydrolysis
Land	Repurposing, reuse, change of use	Brownfield recycling	-

Source: Author's own.

2.2. Expert Workshop and Deductive Analysis

The second stage of the analysis was an expert workshop. The first aim was to test the coding framework developed from the literature analysis. The second aim was to identify the common challenges to looping actions, across resource types, in cities. The workshop involved 60 experts who were sub-divided into 6 focus groups. The experts were from a range of sectors dealing with water, material waste, energy, infrastructure provision, property, land-use planning and urban management. They were largely technical experts (engineers, urban planners, utilities, waste management, environmental and property consultants) or policy-makers with experience in implementing looping actions in European cities.

There was mix of more strategic and detailed technical insight from across the groups. The groups were asked to discuss the challenges to implementing resource reuse, recycling and energy recovery in respect to all five resource types. They were also asked to highlight the common challenges to implementation across resource types. The discussions were recorded. The transcripts were analysed using the coding framework generated by the literature (i.e., deductive context analysis). Some additional challenges emerged from the transcripts which were added to the coding framework and common challenges were identified.

2.3. Comparative Case Studies

The third stage of the analysis used comparative case studies. The aim was to determine how urban context influenced challenges to implementing one nexus (integrated, multi-resource looping) solution. The focus of the research was the Swedish Ecocycles model (ECM). This was the first planned, infrastructure-based, example of a nexus solution in the world. The model has been introduced in Swedish and Chinese cities. Thus it provides the opportunity to determine how the challenges to implementing looping actions and nexus solutions vary with context. Technical experts (architects, engineers, urban planners, energy, water and waste management experts, academics) directly involved in the implementation of ECM (or monitoring of the process) were interviewed to determine what the challenges to implementation had been. The 11 in-depth and 4 focus group interviews were recorded and the findings were triangulated using a range of secondary data sources (technical reports, academic papers, media coverage). The transcripts and secondary data were analysed using deductive content analysis, based on the challenges coding framework generated by the first two stages of the research. The variation in challenges with context for each case were recorded and analysed.

3. Challenges to Looping Actions in Cities

Fifty-eight challenges to looping actions were identified by the literature analysis and expert workshop, across eight themes (socio-cultural; economic and financial; information; regulatory; political, institutional; environmental and technical—Figure 1). Many of the challenges identified by the literature analysis were also highlighted by the expert workshop. So to avoid repetition the results have been presented together.

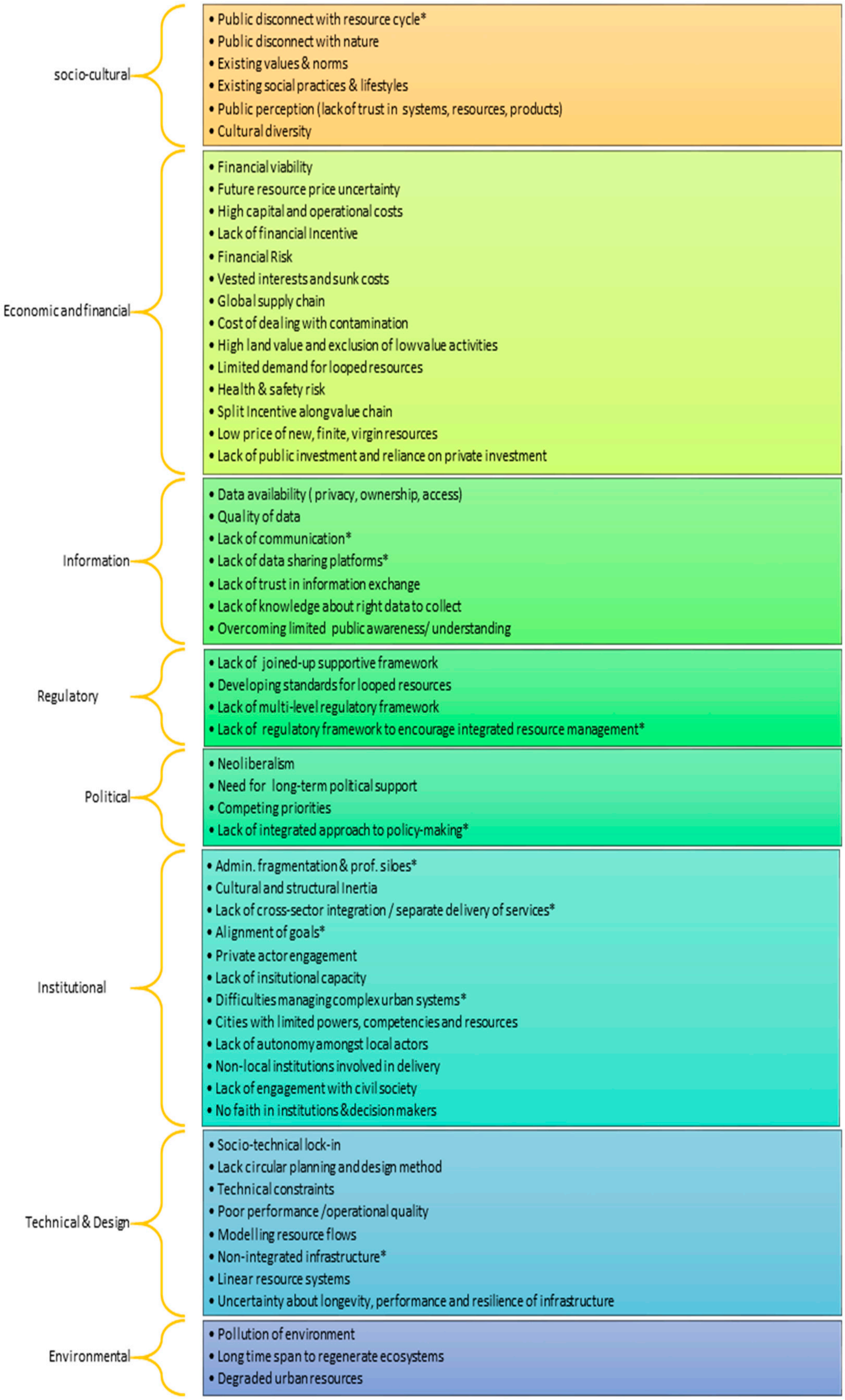

Figure 1. Challenges to looping actions identified by the literature and experts. Source: Authors own (* indicates challenges to nexus solutions).

3.1. Socio-Cultural Challenges

Cities are centers of consumption and production. The cultural values, norms, social practices and lifestyles of those inhabiting the city will influence the reuse, recycling and recovery of resources. Existing cultural norms create a major challenge to looping practices for materials, water, infrastructure and land. Materialism and individualism have powered economic growth and produced a culture of individual consumption (e.g., increase in private car use and one-person households) which impacts on resources and production of "waste" in cities [18,19]. It has also resulted in the devaluation of recycled and reused resources and emergence of the "throw-away" society [20–22]. Existing systems of provision tend to reinforce this by operating linearly [23,24].

The cultural value placed on "wasted" (under-utilised) resources (e.g., vacant land and properties, derelict infrastructure, grey-water) and looped resources needs to be addressed [22,23]. In an era of economic rationalism, it appears that "waste" can only be valued when it is profitable [25].

> *"Yet empty properties can provide affordable spaces for new uses. Historic buildings can be refurbished and repurposed to protect cultural heritage". [26]*

> *"Vacant land offers ecosystem services which are critical to the effective functioning of a city". [27]*

> *"In arid climates grey-water recycling presents a life-line for urban populations". [28]*

The economic value of these resources may be limited, but the social, cultural and environmental value is significant.

A lack of connection between those living in cities and the natural environment [29] reinforces the current values system. Globalisation of services and resource flows means that the environmental impacts of consumption (materials and energy) are often felt at a distance [30,31]. This impairs urbanites understanding of their environmental impact and reduces motivation for values to change. In addition, poor understanding of resource cycles (e.g., water, phosphorous, nitrates, carbon, etc.) and product life-cycles reduces society's willingness to change their values [32].

> *"In my experience people living in cities are far removed from the natural world and its rhythms". [27]*

> *"Residents don't understand if they pave their gardens to park cars it will create localised flooding". [26]*

These values are further reinforced by public concern relating to the siting of waste recycling centers, reprocessing plants, bio-refineries, energy facilities or industrial development within neighborhoods

> *"In our area there is a great deal of local opposition to blue infrastructure, waste recycling and incinerators. Some of the concerns are well founded. But much of the opposition is due to a lack of awareness of the real impact of these schemes". [33]*

Tackling how people value recycled, reused and recovered resources, and involving them in decision-making, is critical to overcoming these problems [34].

Cities bring together people from a variety of cultures. Cultural diversity will impact on the of values, social practices and lifestyles adopted by those living in cities. It can create variability in the success of adopting pro-environmental behaviours, including reuse and recycling of products and materials [35–39]. It will also affect peoples' willingness to consume recycled, reused and recovered resources [35].

> *"We have found that cultural attitudes impact on the way people view waste; how they view their responsibility for waste; and their recycling behavior. It means different approaches are needed to engage people in reuse and recycling". [40]*

Thus, a pluralistic approach will be needed to encourage the adoption of looping practices and products in cities.

3.2. Economic and Financial Challenge

"Lack of financial viability is a key barrier to recycling materials, infrastructure, land and water". [27]

The financial viability of establishing systems of provision which facilitate looping actions are largely challenged by the lack of economic value in recycled, reused or recovered resources and "waste" resources. The low economic value results from a lack of demand for "waste" or looped resources, with the possible exception of recovered energy.

"There is just no demand particularly for recyclates". [40]

"Brownfield sites (outside major cities) are unwanted because of the additional cost of improvement". [26]

"The commercial sector prefers new office buildings; it limits their risks when leasing them". [41]

"It is easier to make a financial case for recovered energy, than for recycled materials, water and infrastructure. There is always demand for energy regardless of the source". [40]

Lack of demand is reinforced by the relatively low cost of virgin materials, finite fossil fuels, new infrastructure and greenfield sites. It is further amplified by consumers concern about the quality of re-used products and materials, and the operational and commercial performance of repurposed and refurbished infrastructure [14,42,43]. Developers tend to avoid brownfield sites in cities because of the potential cost for improvement and the difficulties of consolidating sites. The economic value of looped resources does not internalise the positive externalities they offer, nor does the price of virgin and finite resources reflect the negative externalities their usage produces.

On the supply side, the scale of financial investment for the new infrastructure required to support looping actions (materials, energy and water) is significant. In cities, this has to be considered alongside the vested interests and sunk costs in existing urban infrastructure [43–45].

"The problem is these new circular systems are expensive, both in terms of capital cost and ongoing operational costs. The question is why replace the existing linear systems if they deliver the services needed". [46]

Financial risk creates another challenge to looping actions for all resource types.

"Yes but it is also about trying to get the private sector to invest and they are not willing to do so because it is risky". [28]

"New systems don't just cost a lot they require people to accept them and change their behavior to be effective". [28]

The cost of decontamination (materials, water and land) and dealing with health risks associated with recycling, reuse and recovery (materials, water, energy and land) adds to operational costs [44,47]. Future uncertainty created by resource price volatility (particularly for fossil fuels and recyclates) and changes to global supply chains, makes investment in new infrastructural systems risky [47,48]. It always takes time for user groups to adapt to new technologies and this may also generate risk. Thus private investors may be less willing to invest in the new socio-technical systems required. However, if the real cost of consuming greenfield sites, virgin and finite resources were paid, then there would be a financial case for investing in the systems supporting reuse, recycling and energy recovery in cities.

3.3. Information Challenges

In the age of smart cities and big data, the amount of information collected is increasing. Information is critical for the transformation of cultural values, social practices and institutions needed to support looping activities. Information helps to tackle limited public awareness and understanding of resource cycles (water, nutrients and materials). Increasing engagement of civil society in the generation of data can produce smarter communities, who actively participate in the transformation process [49]. Data provides urban politicians and managers with the technical evidence that transformation is needed and that regulation is effective [11,14,15]. Equally data is needed to help overcome the public's limited awareness of their resource consumption (energy, water and materials), waste production, and its wider implications [50–52]. Technically data enables suppliers to exchange, reuse, recycle and recover resources effectively. However, collecting comprehensive, consistent, useful data for resources in cities is a major challenge.

"We are trying to develop a circular economy in our city. We realised that we would need to map the resource flows to do this. We employed a company to model the flows, but they are having real problems accessing any data. Many actors are unwilling to provide information; much of the information we have got is too aggregated and there are gaps in it". [53]

Data monitoring urban metabolism has been collected for only a few cities worldwide. Interpretation issues exist due to a lack of common conventions [54–56]. Most urban metabolism studies use highly aggregated data—often at the city or regional level—that provides a snapshot of resource or energy use, but no correlation to locations, activities, or people [57]. There is a high data requirement for monitoring resource flows; a lack of follow-up and evaluation of the evolution of a city's urban metabolism and difficulties in identifying cause-and-effect relationships of the metabolic flows [58]. Data for vacant land and buildings is generally collected separately. Similarly, it is highly aggregated and often incomplete, as exemplified by the London *Brownfield Sites Review* [59].

Issues around data ownership, privacy and commercial competitiveness restrict access to urban data [60–62]. The quality of the data produced is also a concern due to limited coverage; inconsistent monitoring and frameworks [11,49]. This reduces trust in the information exchanged [63]. The platforms (virtual or non-virtual) for communicating and sharing data can be useful, but they are highly dependent on the quality of the data they provide. Certainly a lack of both can create a real challenge for looping activities [64,65]. Thus monitoring and managing urban resource flows is difficult.

"A big question for us is what data do we need? We could save ourselves a lot of time, money and heartache if we knew the answer to this". [66]

3.4. Regulatory Challenges

Many layers of regulation affecting resources coalesce in cities. Within Europe the policy framework at a macro-level is well developed and is supportive of looping actions. Circular economy is the focus for the vision for a competitive Europe [67]. This is further supported by the *Europe 2020 Strategy* and the *Roadmap for a Resource Efficient Europe initiative*. However, the legislation at an international level remains sector specific (e.g., the Water Framework Directive, Energy Efficiency in Buildings Directive, Waste Framework Directive) rather than integrative and this is often reflected in national legislation. At a local level this regulatory framework tends to reinforce siloed-thinking and sector specific strategies for managing resources in cities. This creates a barrier to cross-sectoral looping actions and nexus solutions. Thus there is a need for joined-up cross-sector regulation.

"The siloed mentality is reinforced by regulation This prevents this delivery of nexus solutions". [68]

Looping activities in European cities are also dependent on regulation in other global regions.

"A lack of coordinated regulation across global regions can also create a challenge to recycling and reuse in cities". [40]

Two examples—material waste and empty properties—illustrate the point. Strict European regulations around increasing recycling rates have incentivised the export of material waste out of Europe to China. This resulted in the loss of valuable resources from European cities [24] and had detrimental social and environmental impacts in Chinese cities [69]. However, the Green Fence Operation in 2013, set new regulatory standards for recyclates entering China [69,70]. In the short-term this change in regulation is likely to lead to an increase in waste going to landfill or being burnt in European cities, whilst in China it will lead to loss of livelihood for the waste-pickers (and disappearance of waste-picker settlements). In the long-term, it could present an opportunity for increasing material reuse and recycling within European cities, once the appropriate infrastructure and markets have been established

Property speculation in Hedge cities prevents the reuse of empty properties [71–73]. This has social consequences, resulting in a lack of access to affordable housing for many working in the cities. This can create service deserts and loss of thriving communities in cities. It also leads to an increase in commute distances for those working in hedge cities, which has environmental costs. There is a concern that unilateral regulation to prevent speculation could lead to a loss of global competitiveness in the cities/countries where this is introduced. Speculation could be tackled by international regulation, however, there is a lack of political will to do so, because of the negative, short-term economic consequences [74]. Both examples point towards a need for a joined-up, multi-level, regulatory framework to encourage the looping of resources in cities globally.

Regulatory standards can be a useful tool for ensuring quality both in the production and performance of looped resources. This provides certainty for regulators, investors and consumers.

> *"We need some standards. Then consumers can see what they are buying and be confident they are getting good quality goods, buildings, water and materials". [33]*

For example, the adoption of a publically visible standard with proven credentials has supported improvement in the public perception of grey-water reuse and helped systems scale-up in cities [42]. Equally standards set for urban mining have helped enable repurposing, recycling and reuse of materials and infrastructure in cities [11,43,75]. However, standards can create a barrier to looping actions. For example, building regulations and conservation standards create regulatory barriers to adaptive re-use of infrastructure [14]. So the challenge in cities is to create a set of standards which indicate the quality of looped resources. This will also help to establish greater economic and cultural value for these resources.

> *"Knowing that refurbished structures, decontaminated land, recycled grey-water are safe is extremely important to future users. So standards can provide some certainty and create demand". [68]*

3.5. Political Challenges

A global shift towards neoliberalism appears to have significantly affected the political framework in which European cities operate. This has influenced policies, instruments and funding decisions in cities. It has changed the number and diversity of actors involved in resource management, altered power relations between key actors, and shifted the municipalities towards a more facilitative role in urban governance. It has resulted in a reduction in public funding for new development (infrastructural projects) and services (waste, water, energy, transport, etc.)

> *"The role of the city is changing, increasingly we are becoming enablers". [76]*

> *"We (cities) have very limited powers or resources, it makes transformation on this scale very difficult". [77]*

Thus, cities are becoming increasingly reliant on privately operated utilities and privately financed infrastructure. Yet the financial and economic feasibility of reuse, recycling and recovery, particularly for materials and infrastructure, has yet to be proven (see Section 3.2). Urban systems of provision will require radical economic, institutional and technological restructuring to deliver looping actions in cities. Such a transformation will require long-term political support and leadership, which is not supported by the current political culture of short-term, market-driven, reactive decision-making.

> *"Increasingly we rely on private actors to deliver services and infrastructure which we (the municipality) would have provided previously, so we lose control". [46]*

> *"Many actors delivering services in the city have no local ties and no sense of responsibility, so they do what they like". [78]*

> *"It is all about the bottom-line with private actors, but we can regulate services and development through contracts". [76]*

Regulatory frameworks encouraging looping actions exist which should spawn public policies to support these activities in cities. Of course some "wasted resources" are not captured by regulatory frameworks e.g., vacant properties and land. Also political priorities may sometimes conflict with looping actions and vary between national and local levels of government.

> *"In London national political support for foreign and corporate investment in property and land markets, has prevented the reuse of vacant property and use of land for industrial activities". [79]*

> *"However, the GLA and local authorities support the reuse of vacant properties to address the lack of affordable accommodation and the release of land for (low value) industrial activities to enable industrial symbiosis, generate local jobs and diversify the economic base in the capital". [80]*

Here conflicting political priorities prevent looping actions. The political case for looping actions could be built if the social, environmental and economic benefits could be quantified. Data to provide evidence of the benefits would offer a powerful political motivation for supporting these practices.

3.6. Institutional Challenges

Institutional capacity will need to be built to support looping actions in cities. New bodies to produce and enforce standards for recycled and reused resources (materials and grey-water) and regulate looping activities are required [42,43]. Institutional structures that support new ownership models which allow the reuse of goods and infrastructure are fundamental to success [43]. Institutions which collect, share, monitor and regulate the use of data needed to encourage recycling of material waste, land and buildings, and the reuse of infrastructure, goods, grey-water and heat are needed [49,60]. Institutions will be required to support learning within industry, commerce and the community in order to change systems of provision, social practices and lifestyles which undermine looping actions [14,45]. There will be institutional (cultural and structural) inertia to change because of vested interests in preserving current practices and minimising risk across all resource types [44]. These will need to be overcome to facilitate looping actions.

Nexus solutions designed to enable integrated resource looping (particularly materials, energy and water) in city-regions present their own specific institutional challenges. The main challenges are integrating urban resource systems and aligning a diversity of actor goals to facilitate looping actions. Cities incorporate diverse sub-systems composed of different infrastructures, urban functions and multiple resource flows [64]. This increases the technical and organisational complexity of integrating the system as a whole and creating relationships for recycling, reuse and recovery. This challenge is further exacerbated by the administrative fragmentation and professional siloes, which undermine the potential for cross-sector integration of resource flows [7]. Systemic, coordinated action is required which cuts across policy sectors, public and private institutional boundaries and state jurisdictions [63,81,82].

The political changes described have also produced institutional challenges. The erosion of municipal competencies (particularly powers of provision and regulation); reduction in municipal resources (e.g., municipal ownership of land, public funding); and the privatisation of urban services, space and infrastructure have significantly reduced the ability of municipalities to leverage the urban transformation process. This could create problems particularly for nexus solutions and low-value, looping activities (e.g., industrial symbiosis).

The private sector is increasingly involved the management of resources in cities. However, private companies are poor at engaging non-state actors in projects and less likely to deliver public benefits than public bodies, unless under a service-based contract [83,84]. Thus, it is less likely that unprofitable transformations enabling looping actions will be driven by private companies, unless it is mandated. This is important because the privatisation of many public services in cities (including energy, water and waste services) may create institutional barriers to the implementation of nexus solutions.

Meanwhile globalisation has increased involvement of global, private actors in the provision (and management) of urban services and infrastructure. This has shifted actor priorities, placing greater emphasis on economic goals (rather than environmental and social goals) guided increasingly by international (rather than local) markets and regulation. In such an environment the challenge is to make a solid economic case for looping actions or create a more robust, multi-level regulatory framework to ensure implementation.

"the shift in power away from local public providers towards global private entities, has also reduced engagement by civil society in local decision-making. This had further compounded the public's loss of trust in local institutions and decision-makers, in part due to our inability to intervene in global markets". [77]

Public engagement and trust in institutions is also declining. Yet public engagement is needed to ensure the widespread adoption of looping practices and effective use of infrastructure. According to the experts:

"the challenge for cities is to retain some local control over infrastructure, land and service provision whilst engaging a variety of private, community and public sector actors in delivery of these targets". [77]

3.7. Technical and Design Challenges

The city can be viewed as a complex socio-technical system, in which infrastructure and urban form has co-evolved with the social practices and lifestyles of those living and working in the city. Circular design and thinking has not been incorporated into these systems. This creates a socio-technical lock-in, which reinforces linear and separated systems of provision [85,86]. Even if there is willingness amongst institutions providing urban infrastructure and services to adopt circular design or integrated approaches, it is practically difficult to alter these infrastructural systems due to the capital cost and disruption generated by such a radical transformation. The implementation of circular, and/ or integrated systems (nexus solutions), requires the development of new cultural values and social practices amongst citizens to support them.

"One of the biggest challenges is how to introduce circular and integrated systems in cities. Of course some elements already exist, but to redesign systems would be hugely expensive. It would also cause massive disruption. Also we have no guarantee that people will use them". [46]

3.8. Environmental Challenges

The urban environment presents a number of challenges to looping actions. The existing infrastructure and layout is often inflexible [11,14,45,87]. The lack of space in cities offers limited opportunities for adoption of circular infrastructure or transformation of urban form to enable circular actions.

"We need to plan for the inclusion of space in cities for the new infrastructure for recycling, energy recovery and reuse" (Expert 1).

"It is important to encourage pop-up activities. This helps innovation and might lead to the adoption of more looping activities within a city" (Expert 5).

Pollution and environmental degradation in urban areas can also create a challenge for circular actions. For example, land contamination reduces the potential for grey-water reuse and land recycling [14,42]. Restoration of these resources and the associated ecosystems services takes a long time, which can also be very challenging to manage in short political cycles [15].

3.9. Common Challenges Identified by the Urban Experts

The analysis of literature and expert workshop findings suggested that challenges do vary with resource type and looping action. For example, more challenges are encountered for reuse and recycling than for energy recovery. The reuse and recycling of materials and infrastructure encounter more challenges than water and land. The expert workshop identified fourteen common challenges to looping actions which affected four or more resource types in cities (Table 2). Of these fourteen, only five challenges cut across all resources and actions. These can be grouped under four thematic headings: political, regulatory, informational and institutional.

Table 2. Challenges to looping activities across resource types.

		Materials		Water	Infrastructure		Land		Energy
Theme	Challenge	reuse	recycling	recycling	reuse	recycling	reuse	recycling	recovery
Socio-cultural	Existing values & norms	x	x	x	x	x		x	
Economic and financial	Financial viability	x	x	x	x	x	x	x	
	Vested interests and sunk costs	x	x	x	x	x	x		x
	Low cost of virgin, finite, new resources and green field sites	x	x		x	x	x	x	x
	Health & safety risk	x	x	x	x	x		x	x
Information	Data availability	x	x	x	x	x	x	x	x
Regulatory	Lack of joined-up supportive framework	x	x	x	x	x	x	x	x
	Lack of common standards	x	x	x	x	x	x	x	x
Political	Lack of long-term political support	x		x	x	x	x		
	Competing priorities	x	x	x	x	x	x	x	x
Institutional	Institutional Inertia	x		x	x		x		
	Lack of institutional capacity	x	x	x	x	x	x	x	x
	Cities limited powers			x	x	x	x	x	x
Technical & Design	Socio-technical lock-in	x	x	x	x	x			x

Source: Authors own.

The reuse, recycling and recovery of resources is not currently a political priority. However, there are many more established political priorities which conflict with looping actions and thus prevent them. Looping actions will need to be prioritised if they are to be implemented successfully. Secondly, there is no multi-level, cross-sectoral regulation which encourages the reuse, recycling or recovery of resources. Nor are there standards which provide quality assurance for the looped resources produced by these activities. Without a regulatory framework which encourages these actions and standards that create value for the resources produced, both will remain financially risky for investors.

A lack of data identifying under-utilised resources and potential beneficiaries in cities makes organising resource looping actions more difficult. Comprehensive metabolic data would help to establish potential synergies in urban systems and thus reduce resource wastage. Finally, cities lack the institutional capacity to deliver looping actions across resource types. Capacity must be built to enable cross-sectoral resource management, monitoring, regulation, learning and engagement of all urban actors in the delivery of looping actions. This analysis perhaps provides a focus and starting point for those nation states and cities wishing to move towards looping actions. By focusing on these five key challenges we may begin to see a paradigm shift towards resource looping in cities.

4. Challenges to Implementing the Ecocycles Model

The final analysis sought to determine the challenges to implementing the ecocycles model (ECM) in Swedish and Chinese cities. These comparative case studies provide the opportunity to research the challenges to a nexus solution in practice. They also demonstrated how the challenges to implementation for recycling and recovery systems alter with context. This is particularly interesting because much of the literature reviewed refers to the European/North American context; whilst the experts interviewed largely implement projects in the European context. Thus, the case studies provide an opportunity to identify challenges in the Chinese context, which offers a new perspective.

The ECM is a multi-resource (energy, materials, water), integrated, cross-sectoral (municipal, transport, industrial, domestic) urban infrastructural system, which enables the recycling of water, reuse of waste material and waste heat, and recovery of energy from waste-water and household waste. Thus, it integrates a number of looping actions across a range of resources. ECM has been operational in Stockholm for nearly 20 years and has evolved during that period as the context has altered. It is now being translated into the Chinese urban context and has been included in the master-plans for several Chinese eco-cities: Caofeidian (Tangshan), Dongli Lake (Tianjin) and Taihu (Wuxi). However, contextual differences between the Swedish and Chinese urban systems are great and thus the challenges to implementation are very different. Fifty challenges were encountered across the three case studies. Significantly more challenges were identified in China.

4.1. Challenges to Implementation in Hammarby

ECM1 (Hammarby—Figure 2) utilises the existing, proven city-wide infrastructure in combination with new technologies (for converting sludge into fertiliser and biogas and technologies for producing renewable energy on-site) to close resource loops, reduce waste and use of fossil fuels [9]. The buildings connected to the system are designed to be energy efficient, some producing renewable energy. In practice, ECM1 has reduced resource consumption and increased the self-sufficiency of the Hammarby district [9]. It produced a 28–42% reduction in non-renewable energy use, a 29–37% reduction in CO_2 emissions, a 41–46% reduction in water consumption and 90% reduction in material waste going to landfill [88].

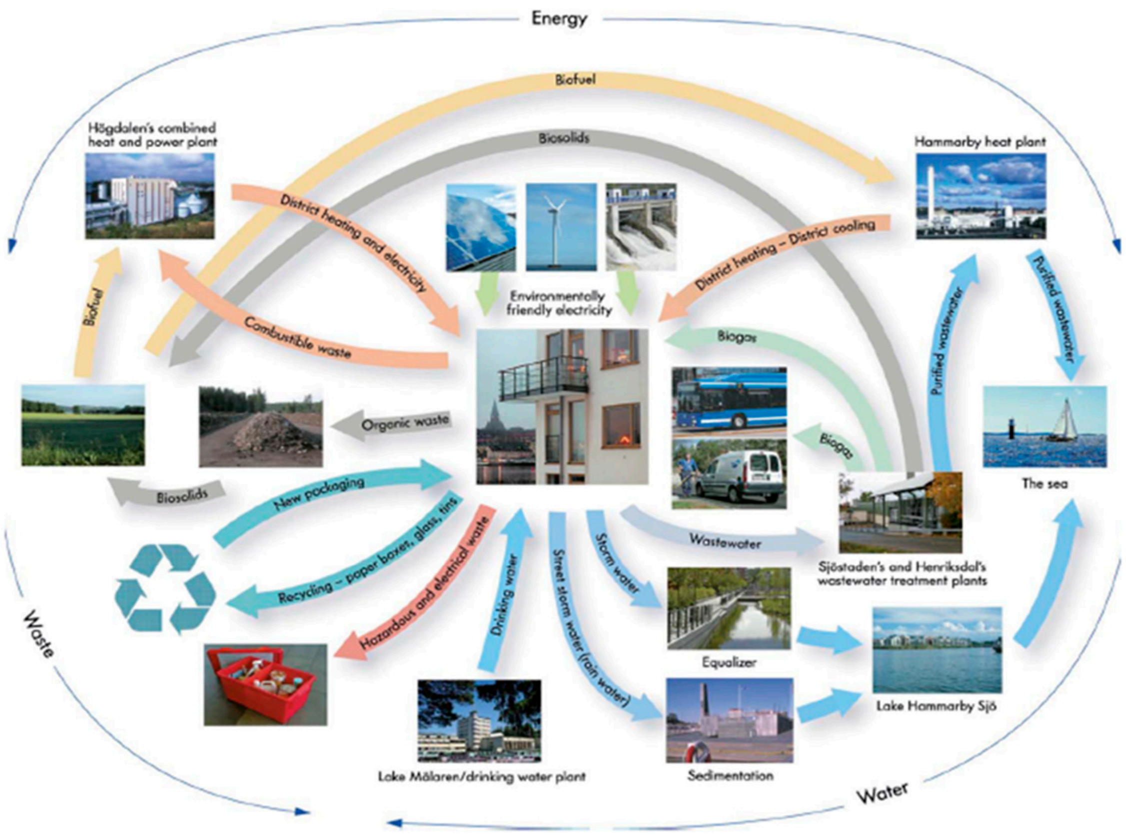

Figure 2. Ecocycles model Hammarby (ECM1). Source: [89].

ECM1 was implemented in Hammarby through a coordinated action across several local government departments (Planning, energy, waste, water and transport departments). Circular approaches had enjoyed long-term political support at a local and national level. Governmental interest in the "natural step" and subsequent adoption of the Alborg Charter (Conference Sustainable Cities and Towns, 1994) embedded these concepts into Swedish cities by 1995 [90]. The development of the Hammarby model was enabled by long-term public investment in the infrastructure underpinning it and additional public funding (including the Local Investment Programme 1998, Swedish delegation for Sustainable Cities 2008 and Climate Investment Programme 2012) [85]. It was further supported by the international and national regulatory framework, particularly the European landfill directive and levy. Initially, the services and infrastructure integral to ECM1 were publically operated. This helped technically with the infrastructural integration and goal alignment between stakeholders involved in the implementation of the system [90]. ECM utilised existing infrastructure which avoided barriers created by sunk costs. The city coordinated the integration of resource streams between urban sub-systems, focused on service delivery (i.e., providing affordable warmth; clean and accessible public transport; reducing waste going to landfill) rather than maximising unit throughput [90]. This approach encouraged a more efficient use of resources.

Nevertheless, political pressure was needed to overcome the initial institutional inertia within government departments to a more integrated response to resource management [90]. The separate and parallel delivery of the services managing resource streams, was reinforced by sunk investment in the infrastructure [90]. Institutionally, concerns over loss of control over systems and difficulties negotiating their integration also created barriers (transaction costs). Initially, the technocrats from different professions found it difficult to communicate with each other effectively and thus identify potential synergies between sub-systems. However, goals for effective service delivery across the city and county councils were largely aligned.

Institutional barriers diminished over time. Trust and understanding was built between actors which enabled the relationships needed to effectively manage ECM to form. Thus, capacity to deliver integrated, circular resource systems developed within the city [91]. The planning process and the strategic plan were used as vehicles for implementing the system and ensuring its longevity. The collaborative planning process was used to engage and build support for the system amongst the service providers and developers. The strategic plan guaranteed that both urban form and the development of new infrastructure would continue to support the expansion of the system [91].

Initially there were concerns surrounding the effective use of the vacuum waste sorting system and the energy consumed by some residential projects on site. It was suggested that a lack of monitoring and enforcement of energy standards, alongside a lack of awareness amongst residents about the effective use of new technologies, were to blame [91]. Thus, educational programmes were organised by the GlasHut (an information centre on site) to raise environmental awareness and encourage a more effective use of the energy and waste systems in Hammarby. Energy consumption was also addressed by post-construction monitoring and enforcement of targets by the local authority [91].

More recent studies have revisited the community and found that the vacuum waste sorting system is extremely effective. However, residents complain that the system for dealing with organic waste is variable across the district [92]. Some blocks have access to a sorting system for organic waste, others don't. This has discouraged the recycling of organic waste, which could be used to produce biofuel or fertilizer, rather than be incinerated (as it tends to be currently). Thus, systems design and coverage affects looping actions.

4.2. Challenges to Implementation in Stockholm Royal Seaport (ECM2)

ECM2 is currently being implemented as part of a major urban regeneration project in Stockholm Royal Seaport (SRSP). ECM2 is also an integrated infrastructural system designed to encourage circular resource flows within the urban district (Figure 3). However, there is a more diverse group of stakeholders involved in the delivery of the system (compared to ECM1), with a range of goals.

Thus, mechanisms for goal alignment and the creation of symbiotic relationships underpinning the infrastructural system have a greater role to play in the delivery of ECM2. Low carbon technologies (e.g., energy-plus houses, electric vehicles) and information technology (e.g., sensors,5G broadband, smart grid and smart apps) will be integrated into ECM2 [85–87]. The data generated from the information system will be used to monitor resource flows (and emissions) and provide information to user groups (citizens and businesses), service providers and regulators within the district. This information will be used to change behaviour amongst users, to improve service efficiency for operators and to enable regulators to ensure proscribed environmental targets are reached [93–95].

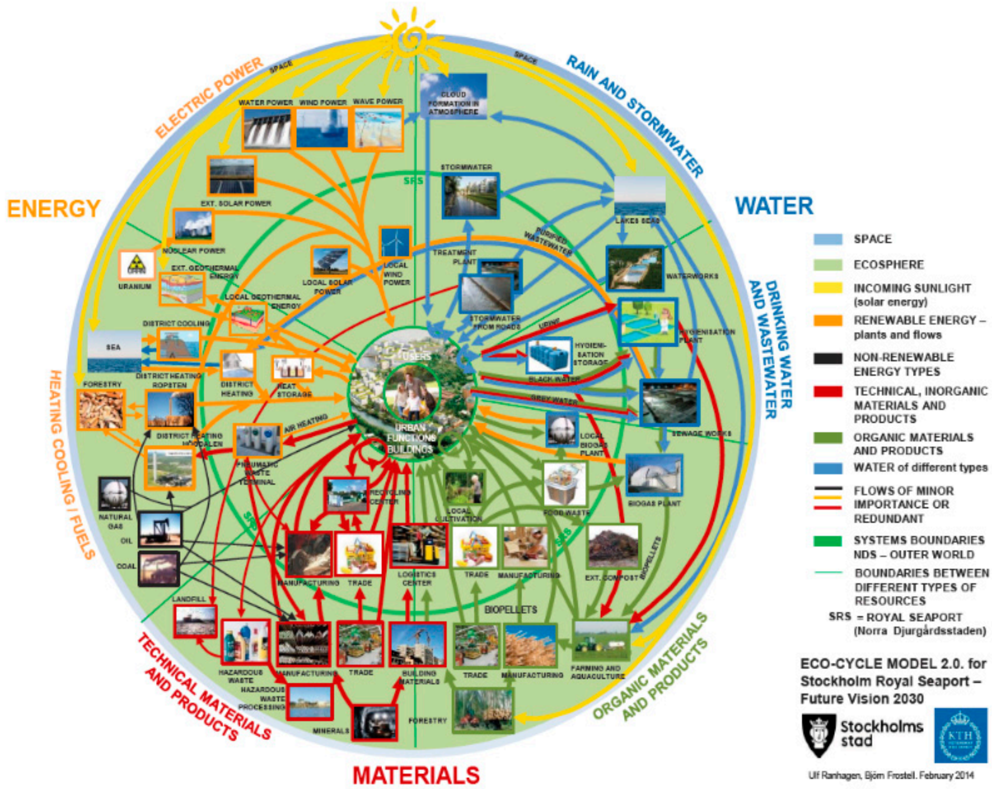

Figure 3. Ecocycles model Stockholm Royal Seaport (ECM2). Source: [95].

The political context in Stockholm altered significantly by the time ECM2 was implemented in the Royal Seaport (SRSP). This created new regulatory, institutional and financial challenges. A political shift (towards a more neoliberal agenda) and regulatory changes (deregulation of energy markets) eroded the competences of the city council (shifting from regulatory and provision functions to enabling and self-regulation), the resources (national funding streams) available to the city, and changed the actors involved in delivery [90,91,93].

By 2011, Stockholm City council's role had shifted from being a regulator and provider of services towards one which was more enabling [90,93]. Public funding for new development projects in Stockholm had significantly reduced [90,93]. Infrastructure projects were more reliant on private finance. Thus, a public–private partnership approach was adopted by the city for service provision and development in SRSP [90,93]. ABB, EnVac, Fortum, Ericcson, Electrolux (many international private sector actors) and a host of construction companies (e.g., NCC, Skanska, and ByggVesta—national private sector actors) provided the buildings, ICT and energy services and waste infrastructure in SRSP. Residents and businesses were engaged in the planning process [90].

Such a diverse group of stakeholders (with local and international interests) also produced a diverse set of goals which needed to be aligned in order to create ECM2 [90]. Of course this has complicated the implementation process. The SRSP development administration provided a platform for communication in the Seaport through the planning process, workshops for citizens and developers, and various online platforms [90,93]. The aim was to build social capital amongst seaport actors, thus building trust and the potential for resource exchange, recycling, reuse and recovery.

The city regulated the outsourced services through contracts and monitored compliance in the built fabric. It used the strategic plan [96] to offer longer-term security for private investors in ECM2 [90]. Nevertheless, the increase in the diversity of actors involved in the delivery of ECM2 created some difficulties in aligning actor interests [90]. The reduction in public funding and public control over the provision of utilities also increased transaction costs and risk to investors [90,93].

A shift in international regulation and national funding, encouraged the private energy company to look at renewable energy alternatives to energy-from-waste, even though the existing socio-technical system supported the expansion of ECM. The grants would help the company offset some of the capital cost. However, the ECM is an integrated socio-technical system which is embedded into the physical and institutional fabric of Stockholm. The degree of integration between urban subsystems and embeddedness creates a socio-technical lock-in to recovery practices in the city.

Information challenges also emerged in the ECM2 project. The fibre-optic network was completed in Stockholm in 2009 providing 4G Wi-Fi internet across the city. This offered the potential to provide information which could be used to change end-user practices [90]. The city planned to use big data to monitor resource flows (particularly energy via the smart grid) and to create smart apps which encouraged pro-environmental behaviour amongst residents and businesses [94,97]. Smart apps for monitoring resource consumption and waste recycling; educating residents; and providing platforms for sharing or exchange of resources are being developed [94]. This potentially increases the system's effectiveness, but it also poses additional challenges around what data to collect; how the data can be shared; data ownership, privacy and quality [94,97]. According to those attempting to model metabolic flows in the city, there are still considerable barriers to accessing the data needed [97].

4.3. Challenges to Implementation in Chinese Eco-Cities (ECM3)

In China the national government is focused on resource efficiency and the creation of a circular economy, largely through technological advances (stated in the 11th Five Year Plan). This is promoted within industrial sectors, industrial parks and eco-cities. However, regulation operates only at an industrial level (i.e., within industrial sectors and industrial parks). Chinese municipalities lack autonomy in the provision of infrastructure and services (they have very limited resources and powers). Private investors (usually developers, businesses and industry), utilities (a mix of state-owned, public–private partnerships and private providers), and the informal waste recycling sector are the key players involved in service delivery in cities [98,99]. Their goals are diverse and non-aligned. There is not a supportive regulatory framework, nor financial incentives to encourage symbiotic relationships to form between actors at the city-scale which could enable looping activities in Chinese cities [98,99].

Municipalities do not act as bodies for service co-ordination, nor offer communication platforms through which key urban stakeholders can form symbiotic relationships. The planning system is ham-strung by the need for municipalities to raise revenue through land leasing [96–99] which means strategically planning integrated circular resource flows is likely to be difficult, because of a clash with competing priorities. Chinese municipalities have a limited ability to leverage private investment in large-scale infrastructure projects [98,99]. They also lack the resources to fund major infrastructural projects themselves, because the tax-sharing system means that they don't have the power to levy taxes [98,99]. So a municipality's capacity to raise funds is very limited. The ECM is expensive so this creates a major implementation challenge.

The revenue of municipalities depends mainly on land-leasing [100–103]. However, cities can also raise tax returns and generate jobs by industrial expansion, the construction of buildings and increasing land values (and revenue) through development [100–103]. Thus, city planners are reticent to place additional environmental requirements on new development as it could mean loss of revenue. So there is a clash of priorities. This potentially creates a problem for aligning stakeholder goals in order to encourage reciprocal relationships to form, especially when a supportive regulatory framework is absent.

A private (often foreign) investment model for the development of Chinese eco-cities has emerged [98,104]. Investors want to pass on the cost of new infrastructural systems to building owners and residents [98]. They prefer small-scale infrastructure (energy, water, material waste) solutions for buildings (or blocks) rather than district or city-wide solutions, as it enables them to pass on the cost and long-term management of the infrastructure to the unit/building owners when the project is complete, thus overcoming the principal agent problem [98,99]. There is also a preference amongst households for systems over which they have more control. They distrust state-owned systems, like the water system which was polluted whilst in state control [99]. Thus, there is no business case for introduction of the ECM.

In 2008, municipal agencies collected and transported 426,450 tons of MSW daily. The majority of municipal solid waste was landfilled (82%), 15% was incinerated and 3% was composted. The situation is further complicated by the informal recycling system which exists in Chinese cities. Approximately 3.3–5.6 million people are involved in the informal waste recycling sector, and are responsible for recycling about 17–38% by weight of Chinese municipal solid waste [105]. This system has proved to be very efficient [106]. However, it removes the valuable recyclates from the waste stream, leaving 60% kitchen residue which is hard to dispose of.

Chinese households do not sort recycled waste. It is not an activity embedded in current social practices. Recycling is also viewed as a low status occupation. Thus, the informal sector is essential for recycling activities to occur. Migrant communities of recyclers have sprung up around major cities in China, but the recent economic down-turn and global reduction in the value of recyclables has threatened the informal industry and the workforce [107]. The sector has been further threatened by the Green Fence Regulation.

The Chinese government prefers to incinerate waste [106], which could fit with the ECM. Four new incineration plants were planned to open in Shanghai, 70% of the city's household waste was to be incinerated [106]. However, incineration is controversial amongst the Chinese citizens, because of the existing problem with urban air pollution. In April 2015, plans for an incinerator in Guangdong province in southern China were scrapped by the city after a mass protest [106]. Nevertheless 249 cities now have incinerators. In addition, land-use zoning laws (and lack of mixed use development) in Chinese cities may make district heating systems more technically difficult to operate because it reduces the proximity of producers and consumers [98].

Amongst Chinese urban technocrats there appears to be a lack of technical understanding of the collaborative, integrated systems planning approach that underpins the successful implementation of ECM [98,107]. The technocrats tend to be professionally siloed and find it difficult to cooperate across sectoral boundaries. The lack of a communication platform to enable cross-sectoral arrangements to develop further exacerbates the problem [98,99]. The planning process in Chinese cities is highly technocratic and not very collaborative [108]. Thus, the Chinese have not embraced the collaborative, integrated planning approach central to the successful delivery of ECM [98,107].

Existing resource systems tend to operate separately and are linear. This is reflected in the infrastructure. In addition, the land use zoning system prevents the mix of uses needed to enable urban symbiosis (although industrial symbiosis is encouraged in industrial parks). Also competing alternative technologies for renewable power generation (particularly solar technology) makes the ECM system a less attractive option for Chinese cities.

4.4. Summary of Results for Case Studies

The case studies tell us something about the challenges to implementing the ECM, looping actions (recycling and energy recovery activities) and nexus-type solutions. They also demonstrate how challenges alter with context (Table 3). ECM was developed for the Swedish and not the Chinese context. In Sweden the ECM fits well within the existing regime in cities [85,109]. However, in Chinese cities it does not fit with the existing regime. Thus it has encountered at least 42 challenges. The key challenges to the ECM in China are: existing (and competing) socio-technical systems; high capital and operational costs; a lack of supportive regulation; a lack of national and city government support; involvement of the informal waste recycling sector and public opposition to waste-to-energy plants. Interestingly the ECM has also encountered some challenges in Sweden. ECM2 has encountered considerably more challenges compared with ECM1. These largely result from the inclusion of more private actors in service delivery, loss of public funding and limited user engagement in the ECM resulting from the passive nature of the system. Thus challenges to implementing the ECM vary significantly between contexts.

Table 3. Challenges to the implementation of the ecocycles model (ECM1, 2 and 3).

Theme	Challenge	ECM1	ECM2	ECM3
Socio-cultural	Public opposition			✓
	Existing values & norms	✓	✓	✓
	Existing social practices & lifestyles	✓	✓	✓
	Public perception (lack of trust in systems, resources, products)			✓
Economic & financial	Financial viability		✓	✓
	Future resource price uncertainty			✓
	Global supply chain			✓
	High costs & financial investment		✓	✓
	Lack of financial Incentive			✓
	Financial Risk		✓	✓
	Lack of business case			✓
	Vested interests and sunk costs	✓		✓
	Lack of public investment and reliance on private investment		✓	✓
Information	Data availability (privacy, ownership, access)		✓	
	Quality of data		✓	
	Lack of communication	✓		✓
	Lack of data sharing platforms			✓
	Limited technical knowledge			✓
	Lack of knowledge about right data to collect		✓	
	Overcoming limited public awareness/ understanding	✓	✓	✓
Regulatory	Lack of joined-up supportive framework			✓
	Lack of monitoring & enforcement	✓		
	No regulatory framework to encourage integrated resource management			✓
	Land-use zoning			✓
	Deregulation		✓	
Political	Need for long-term political support			✓
	Competing priorities			✓
Theme	Challenge	ECM1	ECM2	ECM3
	Neoliberalism		✓	✓
Institutional	Admin. fragmentation & prof. siloes	✓	✓	✓
	Cultural and structural inertia within institutions	✓	✓	✓
	Lack of cross-sector integration/separate delivery of services	✓	✓	✓
	Alignment of goals		✓	✓
	Private actor engagement		✓	✓
	Lack of institutional capacity for transformation			✓
	Difficulties managing complex urban systems	✓	✓	
	Cities with limited powers			✓
	Erosion of municipal competencies and resources		✓	
	Lack of autonomy amongst local actors		✓	✓
	Non-local institutions involved in delivery		✓	✓
	Lack of engagement with civil society	✓		✓
	No faith in institutions &decision makers			✓
	Informal institutions			✓
	Privatisation services, space, infra		✓	✓
Technical & Design	Socio-technical lock-in			✓
	Technical constraints		✓	✓
	Non-integrated infrastructure	✓		✓
	Linear resource systems	✓		✓
	Poor coverage and access to systems	✓		
	Socio-technical lock-in created by integrated systems		✓	
	Competing alternative technologies			✓
Environment	Proximity of producers and consumers			✓
Total Challenges		14	24	42

Source: Author’s own.

The context also affects the challenges to looping actions (recycling and recovery). In Sweden the main barrier to recycling is the effective and widespread system of energy recovery (i.e., the ECM). Recovery fits with the existing socio-technical system in Sweden, provides stable and high value returns and requires limited public engagement in the process. In China the existing system for recycling municipal waste is hampered by the involvement of the informal sector (which separates out the high value recyclates) and a lack of public engagement in recycling. For both countries the volatility in the markets for recyclates creates a major challenge for further development. In contrast energy has a guaranteed value, thus recovery is a less precarious option. However, as demonstrated in China, there are other challenges to energy recovery, including public opposition and land-use zoning policies.

We can also learn lessons from the application of ECM in China and Sweden for nexus solutions. The Swedish experience suggests that long-term political support for integrated, looping approaches to resource management would be needed for a nexus solution to be implemented successfully. It would also require regulatory and financial support. Both would help to leverage goal alignment between actors in the nexus chains. The absence of political, regulation and funding support in Chinese cities, is partially responsible for the problems faced in implementation.

Institutions whose culture and structure support integrated resource streams and looping activities will also be needed to implement nexus solutions (demonstrated by ECM1). These goals should be built into institutional thinking, design, planning, operational and investment decisions. A common language to enable communication and build trust between sectoral siloes is also required to support nexus solutions. Information sharing between actors will be critical for success. The Swedish context supports nexus solutions. However, in China we see that the political, financial, regulatory and institutional requirements for the successful implementation of nexus solutions are currently lacking.

5. Conclusions

This paper has identified a range of challenges to implementing looping actions. Some of the challenges relate to the need for systemic cultural change in society and the restructuring of the economy to support looping activities. Others relate to the difficulties in developing the levers—regulatory, institutional, educational, technical and political—needed for that transformation to occur.

The literature analysis and expert workshop have identified 58 challenges to looping actions in cities (Figure 1). However, the challenges vary with resource and action type. More challenges are faced by reuse and recycling activities than for energy recovery. Nevertheless, there are five challenges which cut across resources and actions: a lack of political support, joined-up regulatory framework and common standards, data and institutional capacity (Table 2). If we initially focus on addressing these challenges, we could maximise our impact on reducing the wastage of all resources in cities.

The case studies reinforce the challenges identified by the literature and expert workshop. They also demonstrate that challenges are likely to vary considerably with context (Table 3). Thus, there will need to be context appropriate solutions. Nevertheless, the literature, experts and case studies also point towards some changes within the regime to support resource looping actions which will cut across contexts.

Firstly, there must be political support for looping actions. Addressing resource "waste" in cities will need to be a priority in order to overcome conflicts with other political agendas. Secondly a multi-scaler, cross-sectoral regulatory framework for the management of resources will be needed to encourage looping actions and prevent conflicts. Introducing a management hierarchy across all resource types (similar to the 3 R's) could help implementation. Common standards for recycled, reused and recovered resources are also needed, particularly to address consumer concerns about health and safety risks. However, standards which demonstrate quality will also encourage a growth in demand across all resource types.

The financial viability and risk of investing in looped resources will also need to be addressed. Standards may help to an extent. However, this will not be enough. An increase in the relative cost of alternatives (new, virgin, finite resources, green-field sites) and guaranteed price for looped resources (particularly materials and infrastructure) at least until systemic capacity is built, is needed. New institutions to enforce the standards and regulation; collect, manage and monitor data; enable learning amongst urban actors; encourage community engagement in looping activities will underpin the delivery of the transformation process.

Urban form which supports looping actions, for example by providing space for looping activities, mixed-uses to enable urban symbiosis, using a flexible/adaptable infrastructure which can be modified to meet the new requirements of urban citizens, should also be adopted. This socio-technical transformation could be achieved over the long-term through a process of urban renewal which engages the urban population, but only if there is the political will.

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