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The emerging role of mega-urban regions in the sustainability of global production-consumption systems

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Mega-urban regions (MURs) are important consumers or traders of resources from, or producers of wastes destined for, the global hinterlands. These roles, coupled with their concentration, clustering and centrality effects, mean MURs have a disproportionately large effect on the sustainability of global production-consumption systems (PCSs). Actions taken within MURs influence the sustainability of global PCSs, and vice versa; but that influence is complicated by complex governance intersections. Three cases are used to illustrate governance innovation in MUR-PCS interactions: industrial symbiosis in Tianjin, China; electricity production in London, UK; and the adoption of standards and labels for seafood in Bangkok, Thailand. In London and Tianjin, waste capture reduced consumption of hinterland resources, whereas in Bangkok, the aim was to improve the sustainability of resource use in coastal and marine hinterlands. We suggest an agenda for research to evaluate the potential for transferrable MUR governance innovation to enable sustainable and equitable PCSs.

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INTRODUCTION

Urban regions cannot be sustained without the support of resources from regional and global hinterlands[1]. Historically, cities, while centers of trade and power, depended on their regional ecosystems and adjacent rural hinterlands for their sustenance. Over the past several decades rural-urban relations have shifted, and global economic integration has led to an expansion and thickening of city dependence on imported resources and global distribution of waste[2], leading to what Taylor[3] terms city 'hinterworld' relations, or an urban reliance on 'global hinterlands'[4]. Urban areas are now responsible for most of the consumption of the world's resources, including about 75% of global primary energy[5] and 76% of wood used[6,7], as well as associated emissions and waste generation[8].

In fact, global urban material consumption is projected to grow faster than the global urban population reaching approximately 90 billion tons by 2050, an increase of 116% in global urban material consumption over the period between 2010 and 2050[9]. Further, just 25 mega-cities produce 52% of the world's urban greenhouse gas emissions[10]. With the number of people living in urban areas and mega-cities on the rise[11], actions taken in these areas become increasingly important to sustainability.

Mega-urban regions (MURs) are an emerging level of spatial agglomeration, often around one or more central cities, that are highly complex and polycentric in their governance[12–18]. Some studies of MURs focus on their geographical and spatial configuration[19], whereas many highlight their functional purpose as nodes of competitive economic advantage, aimed at attracting global capital flows and private enterprises[20,21].

Recognizing global flows of people, finance, resources and information, an emerging group of scholars have coalesced around an approach to advancing sustainability focused on points of leverage in Production-Consumption Systems (PCS)[22]. A PCS takes a global perspective and is defined as a system that connects environmental goods and services, individuals, households, organizations, and states through linkages in which energy and materials are transformed, utility is derived and relationships take place[23]. By focusing attention on the linkages between production, distribution and consumption activities which may be widely separated in space[24], a PCS perspective bridges (or complements) more place-based perspectives, such as those provided by urban metabolism studies of particular cities, with the insights from footprint approaches that acknowledge impacts on other locations[25], and political-economy studies of commodity chains that consider added-value and power[21]. The PCS perspective reveals points of leverage to improve sustainability that may lie with actors or institutions having influence almost anywhere along those supply and value chains[21,26], a key message also made by urban studies of teleconnections and telecoupling[27–29].

MURs have a disproportionately large role in the sustainability of global production-consumption systems because of the effects of concentration, clustering and centrality. The dense convergence of people within MURs concentrates natural resource use and pollutants and wastes, making more visible the consequences of production, distribution and consumption actions, which, in turn, can lead to pressures to address the associated concerns within the region[17,30–34]. MURs cluster, through the process of agglomeration, a large mix of functions and services in relatively close proximity, creating access to diverse resources, including economic, knowledge, and social capital, as well as policy and manufacturing capacity[13,35,36]. This access, in turn, can create opportunities for cross-sectoral flows that close resource loops and reduce dependence on imported resources, however, the polycentric nature of their development can also create situations of contested governance[18,37] effectively resulting in large scale collective action problems[38,39]. MURs are also typically key logistical hubs with high centrality in the inter-city production-

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consumption systems that span the globe by air, rail, roads, information highways and energy networks[14,15,40–43]. With more materials and information passing through them, a MUR's leverage and influence is correspondingly high[44].

To advance the theoretical grounding, and by combining these different strands of scholarship, we infer that, in a stylized way, mega-city regions can be thought of as having three roles in production-consumption systems: (1) consumer, (2) producer, and (3) trader (Fig. 1). Within any given MUR, consumption occurs at the individual, household, firm and state level, placing demands on resources in hinterlands near and far. Urban metabolism and footprint studies seek to better understand the material implication of this role[25,45], however there are additional functional and stakeholder-based characteristics that are encompassed in its definition here. As pools of labor, MURs can be the locus of production, and they draw on inputs from elsewhere to manufacture products with environmental burdens within the city and in other locations where they are transported for use[46]. Finally, MURs can become nodes of trade and investment between other locations, thus acting as traders of both physical materials and directing materials and goods elsewhere through capitalization[47]. This implies within each of these categories, there are PCS innovations aimed at advancing sustainability.

This paper addresses two main objectives: (1) identifying the nature of and impacts resulting from the interactions between mega-urban regions in these three roles and production-consumption systems, and (2) understanding how these MUR roles inform potential innovations in PCS governance while advancing global sustainability.

RESULTS

Assignment of MUR roles

To address the research questions, we use a set of three exemplary case studies which are summarized in Table 1, in order to inductively develop the governance and sustainability implications of the conceptual framework in Fig. 1. In each case, the MUR is assigned one of the three MUR roles (consumer,

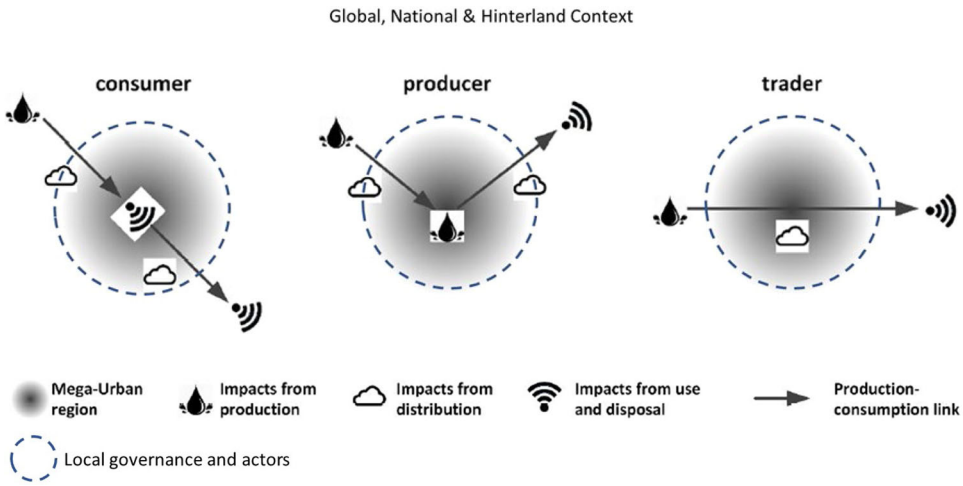

Fig. 1 Mega-urban regions can act as consumers, producers or traders in their interactions with production–consumption systems with consequences for environmental impacts within the urban region and in local and global hinterlands, raising multiple issues for the governance and pursuit of sustainability. Shaded region = mega-urban region; droplets = impacts from production; cloud = impacts from transportation; ripples = impacts from use and disposal; arrows = production–consumption link; dashed line = local governance and actors. Note: Feedbacks are not reflected in the figure but also exist within the system.

Table 1. Summary of the key features of the three case studies.

MUR	London	Tianjin	Bangkok
Global PCS	Biomass fuel	Industrial materials	Seafood
Case	Replacing imported biomass fuel with local waste heat as source of energy	Industrial symbiosis	Sustainability standards and labels
MUR role in PCS	Consumer	Producer	Trader
Population in 2015 (millions)[a]	8.7–10.2	15.5	10.6
Hinterlands Impacts	Land-use and atmosphere	Land-use and atmosphere	Coastal land, marine and atmosphere
Governance Innovation	City government pushes for lower emission fuels	Boundary organization facilitates match-making between industries	Public-private mix sets or adopts Minimum and Voluntary standards and labels
Operational Approach	Decentralized energy at prices lower than from national grid	Smaller number of supply chains	Leveraging the pull of retailers & brands
Impacts	Reduces reliance on hinterlands Reduce GHG emissions	Reduces reliance on hinterlands Reduce GHG emissions Reduces amount of raw materials, reduces solid waste.	Aquatic Hinterlands used more sustainably Demonstration value to other firms/sectors of carbon-footprinting

[a]MUR spatial and population data can vary based on agency assessments.

producer, or trader), which, we acknowledge is a simplification of the multitude of roles each MUR likely represents.

London

Attracting dense concentrations of consumers – household, corporate and state – MURs place demands on resources in hinterlands near and far. The use and disposal of products consumed also contributes to negative environmental impacts in the city region and distant hinterlands. In 1921 London's electricity production-consumption system was fairly localized, with over seventy power stations located within the city itself, and coal mines less than 100 miles to the northwest. However, over time, the PCS changed as consumption of electricity rapidly grew, and energy production grew beyond London's localized boundaries to impact regions around the globe.

Sustainable consumption initiatives look to reduce impacts by using fewer products or using products which create smaller impacts when they are made, and by generating less waste. In London, concerns firstly with public health and then greenhouse gas emissions, saw the elimination of coal production followed by an increase in coal imports[48], and then a significant transition towards renewable sources, including the conversion of coal-fired power plants to dedicated biomass thermo-electric plants (Table 1). In meeting the electricity consumption demand of London, government policies of the United Kingdom to address global warming were important, starting from the Kyoto Protocol. The UK Climate Change Act in 2008, committed the government to reduce emissions by at least 80% by 2050 from 1990 levels, with at least a 34% reduction to be achieved by 2020. The UK is also subject to the target included in the 2009 Renewable Energy Directive to achieve 15% of its energy consumption from renewable sources by 2020[49]. The primary supplier of wood pellets to the UK is the United States, specifically from forests located in the Southeastern portion of the US, which exported 1.56MMTs valued at US$310 million as of 2013[50]. The first conversion from coal-fired plants occurred in 2011, and there are now 46 dedicated biomass power plants in the UK; with a combined installed capacity of 2885 MW[51], which accounts for over 36% of the total electricity share of the UK as of 2014[52]. While the use of wood pellets has decreased CO_2-eq emissions at the power plants, it takes 1892 km^2 or 189,200 hectares of forested land in the Southeastern United States to meet the wood pellet importation requirements of the UK, with the global warming potential impacts of just importing 1.56MMT of wood pellets from the US to the UK (2013) being 2.48 $\times 10^8$ kg[53,54]. The recent goal to achieve national CO_2 reductions through localized energy production would reduce such impacts on global hinterlands. The Greater London Authority (GLA) is now moving towards a decentralized supply based on locally capturing waste heat, reducing the MUR's reliance on both regional and global hinterlands.

The GLA has also pursued demand-side management including energy efficiency programs. The Decentralized Energy Project Development Unit (DEPDU) is a boundary organization that supports the Energy Independence plan for London in its role as a consumer MUR[55], which set a target of 25% of London's energy needs being sourced from local decentralized energy sources by 2025. To become the first public authority to receive a 'junior' electricity license so the city could generate its own electricity, GLA formed unique alliances with utility authorities, private industry and NGOs. With €3.3 million in funding, DEPDU has invested in combined heat and power energy generation, and waste heat capture from underground data centers and industrial processes. The national policies to decrease carbon emissions required significant shifts in technologies, yet the existing national policies initially hindered the creativity of local jurisdictions to implement innovative solutions. The largest of these barriers centered on the ability of local government to purchase excess electricity generated within local boundaries. This barrier was overcome through the collaboration with the non-ministerial Office of Gas and Electricity Markets, which, in 2009, modified the rules for small generators to supply electricity under a tariff agreement that provides economic incentives to small suppliers, that also proved attractive to investors.

Tianjin

As pools of labor, MURs draw on inputs from elsewhere to manufacture products with environmental burdens within the city and in other locations (producer, Fig. 1). Apart from large firms, small and medium sized enterprises and households may also contribute significantly to the production role in some MURs and PCSs. Clean production initiatives look to reduce impacts locally by being more efficient, requiring fewer raw materials and producing less waste or pollution, and designing products so they are easier to maintain, reuse and recycle[56]. Highly industrialized MURs may also look at ways to close resource loops and re-use waste streams within production activities by taking advantage of the clustering of production activities. In Tianjin the sustainability challenge was to capture waste streams and turn them into resources, thus reducing costs and impacts on hinterlands and local environments. In this case it required the creation of a boundary organization that could link small and medium sized enterprizes to each other, and the national government's support for the circular economy. The Tianjin Economic-Technological Development Area (TEDA) was established in 1984, and is one of China's first industrial development zones. The Eco-TEDA program was launched in 2009, to support material, energy and logistic exchanges among industries in order to optimize resource use and minimize waste within TEDA[57,58], reducing impacts on hinterland resources. Between 2009 and 2014, the Eco-TEDA industrial symbiosis project, supported by the EU's SWITCH-Asia program, UNIDO, and the UK's International Synergies, involved over 955 small and medium-sized businesses including manufacturing enterprises, recyclers, and technology and services providers, with 625 of these SMEs joining the industrial symbiosis network[59]. The TEDA Eco-Center was the key boundary organization that supported the industrial symbiosis network development and catalyzed the cultural change necessary to advance eco-innovation[60,61]. Important activities of industrial symbiosis coordinators include the identification of possible synergies, facilitation of inter-firm collaboration and research partnership, and development of monitoring and network systems[62–64]. Many of these industrial symbiosis programs are catalyzed by effective group process design, resulting in enhanced ease of replication and transferability across IS programs[62]. The industrial symbiosis project diverted 1.43 million tons of waste from landfill and reduced carbon dioxide emissions by 167,000 tons in the initial phase through 2014[59]. These synergies circulated resources within TEDA, shortening supply chains and decreasing the quantity of imported resources such as steel. For example, one TEDA synergy connects fabric producer, Fiberweb, with Toyotsu Resource Management Company Limited, to process 20 tons of waste zinc-plated steel and stainless-steel pipes for recovery and reuse[59,65]. This steel recovery lowers industrial impact by shortening the supply chain and reducing CO_2 emissions[66]. Another example is the reduced greenhouse gas emissions achieved in the diversion of 12.5 K tons per year of excess CO_2 and hot steam created by Terra Nitrogen, an ammonia producing company, and used by vegetable grower, John Baarda, in an expanded set of greenhouses for plant growth and tomato production[67].

The Tianjin local government played a critical role in catalyzing exchanges among TEDA businesses and encouraging collaboration among firms by providing policy incentives for active industrial symbiosis participants. With the local government

legitimizing the industrial symbiosis project, businesses provided material and energy flow information to the Eco-Center that led to collaborative exchanges[64,68]. The Chinese Federal Government programs on the circular economy were another important driver for industrial symbiosis in Tianjin. The Circular Economy Promotion Law from 2009 includes policies and instruments to decouple economic growth from resource consumption and pollutants and serves as the basis of a 'new development model' for China[56,68,69].

In Tianjin, the primary driver of participation in industrial symbiosis is the economic benefits derived by participants, with the industrial symbiosis project leading to 73 million RMB in cost savings and 112 million RMB in revenue[59]. At the same time the industrial symbiosis project faced a sustainability challenge once funding and facilitative support of the EU SWITCH-Asia Programme, UNIDO and International Synergies ended. To address this challenge, the Tianjin Industrial Symbiosis Innovative Technology Alliance was formed in 2011 with 17 TEDA companies and the Eco-Center as its secretariat, supported by the Tianjin Municipal Science and Technology Commission[59]. The Alliance has provided some support on match-making events, but there is not the same level of activity since 2014 without active local government involvement and the profile of international involvement. The Eco-Center remains central to the continued development of synergies among businesses.

The TEDA boundary organization must maintain accountability to both governments and the firms it serves. To do so, information is crucial to its functions. Industrial symbiosis exchanges themselves are impeded by a range of factors, including an unclear classification of waste among businesses and lack of enforcement of existing environmental and social regulations. This is compounded by a lack of availability of resource and waste information within small and medium sized businesses, and a hesitation to share available data with the coordinating body for competitive and regulatory reasons. Even where data exists, the challenge lies in analyzing synergy opportunities across a complex number of sectors, and the fact that data about imported resources and waste are disconnected and not analyzed as an integrated materials system[66]. TEDA itself was not designed for resource exchange, which results in infrastructure challenges in supporting synergies[65,68]. Similarly, the businesses themselves had weak environmental management capacity, and lack connections to other industries which the industrial symbiosis project and facilitating bodies aim to address.

Bangkok

Logistically well-placed MURs, as their service sectors grow powerful[41] may also become nodes of trade and investment between other locations (trader, Fig. 1). Sustainable sourcing, trading, and investment initiatives seek efficiency gains that help to minimize environmental impacts through intelligent logistic choices. The Bangkok Metropolitan Area (Table 1) is surrounded by a belt of manufacturing and industrial provinces that merge with it and form an agglomeration known as the Greater Bangkok Region (GBR). The GBR potentially has huge leverage on the sustainability of PCSs particularly in its trader role. The seafood sector illustrates this potential. Thailand is the fifth largest exporter of seafood products in the world. In 2012, Thailand exported 1.9 MT of seafood products worth US$8.8 billion, of which about US $2.6 billion came from tuna and US$1.6 billion from shrimp. Based in Bangkok, Thai Union, for example, is the global industry leader in tuna products – almost half of its annual revenue of around US $5 billion in 2014 was from tuna alone. The Charoen Pokphand Group, the largest private company in Thailand, with annual revenue of around US$46 billion, is a major shrimp producer and exporter. Recurrent concerns have been raised by international NGOs about the environmental and social impacts of the capture fisheries and aquaculture on marine and coastal hinterlands where the seafood is sourced[70]. The Marine Stewardship Council, certifies about 10% of the global total of wild-caught seafood as being sourced from sustainable fisheries. Around 5% of world aquaculture production is certified by third parties like Global Aquaculture Alliance's Best Aquaculture Practices certification – a scheme backed by the world's largest retailer, Walmart – or, the Aquaculture Stewardship Council accreditation. In 2015, Thailand received a 'yellow card' from the EU for workplace practices in the fisheries sector. At the same time, Thai Union, was targeted by Greenpeace for destructive and wasteful fishing practices. During 2015 The Guardian, among other medias, published influential stories on slavery and trafficking of people who work on Thai fishing boats[71]. By the same token, the Charoen Pokphand Group was accused of buying fishmeal from fishing boats manned by slave labor[70]. In response, the government of Thailand in 2016 negotiated an agreement with seafood companies – including Thai Union, Charoen Pokphand Group, and key industry associations – to end forced labor in seafood supply chains. Additional concerns were raised by EU and other importing countries about food safety arising from antibiotic residues[72].

In response to the concerns raised, the Thai government threatened regulation and ultimately negotiated minimum standards with key firms in the industry, while firms with dominant roles in seafood commodity chains promoted and adopted voluntary standards to manage risks to their reputation. For firms in Bangkok, standards are used to help manage risks to exports. The national government agency, Thailand Greenhouse Gas Management Organization (TGO), reached out to Thai Union to include one of its prime or 'symbolic' export products, the "Green Curry Tuna", as one of the three pilot commodities for a new carbon footprint label. Soon after, the Charoen Pokphand Group also acquired carbon footprint labels for two of its 'champion' products, both based on shrimp dumplings, one of which also received a carbon footprint reduction label from the TGO. While the TGO's work demonstrated the technical feasibility of carbon-related eco-labels for processed seafood, the actions taken so far by seafood firms are primarily symbolic. The incentives to participate in carbon footprint schemes remain unclear, whereas for fisheries standards, there may be little choice if producers wish to maintain access to markets. In fact, some retailers in Europe, under pressure from consumer and labor groups as well as shareholders, train, audit and make purchasing agreements directly with individual farms in Thailand following their required practices.

The effects of sustainability-oriented standards and labels – whether related to fishing practices or carbon footprints – on consumption of processed seafood within the city region, were small relative to consumption elsewhere. In the case of tinned tuna, for example, of the 206 thousand tons produced in Thai factories in 2013, only 14% was sold in Thailand. In the case of shrimp, domestic consumption only accounted for about 5% of production. The adoption of standards, it should be reiterated, was more driven by demands of retailers and consumers in the EU, US or Japan, than local consumers or the Government of Thailand. The important regional hinterlands for farmed shrimp was coastal areas in Thailand, and for tinned tuna it was ocean fisheries. A more significant impact of the 2009 pilot carbon footprint was the demonstration of a major firm successfully completing the process. As of March 2016, the carbon footprint label was used by 35 firms covering 136 products, of which 4 were seafood products.

DISCUSSION

The impacts resulting from the interactions between MURs and PCSs differ in type and magnitude and can follow complex trajectories. The three case studies provide some initial insights into potential levers of change and opportunities for future

research. In particular, we highlight four key areas where MURs can impact change in PCS: governance innovations, transboundary stakeholder engagement, social & environmental justice, accountability, and legitimacy, and finally, drivers and incentives. These, in turn, indicate future challenges and opportunities for MURs in the governance of PCS.

Governance innovations opportunities stem from the fact that global PCSs are long, and the administration of MURs is often fragmented and polycentric. This suggests that governance at the intersection between PCS and MURs will need to be nuanced and innovative to be influential and contribute to sustainability. Examination of the three cases combined with a literature analysis has shown that among the challenges present in PCS innovations in MURs are those of appropriate and effective governance. There are a number of ways that governance plays into the effectiveness of PCS, as has been demonstrated across a variety of literatures[18,21,24,25,40,54]. This includes the mismatch between governance at the MUR level, and the larger geopolitical context of the PCS which often stretch across regional and national boundaries[40]. The hinterland impact on United States timber production resulting from London's effort to reduce local greenhouse gas emissions is one example of this mismatch in governance. Scale mismatch in turn gives rise to issues around conflicting policies from different actors in the system[18,73], the transparency and degree of information available to actors in the PCS[43], and the legitimacy and accountability of these actors and their decisions.

The transboundary nature of PCSs also creates challenges for access and social justice, as actions in one place can create negative impacts elsewhere and aligning incentives can be difficult. This is especially evident in the Bangkok case where voluntary, but largely symbolic, measures were adopted by major firms to reduce reputational risk and maintain global market access. Policies on the part of MURs that are able to more effectively enable collaboration among stakeholders can create strong incentives (regulatory, economic, and normative), improve transparency and accountability, and address issues of access and social justice, and have been shown to help improve innovations for sustainable PCS. This potential was evident in the producer case with the work by Eco-TEDA to facilitate industrial symbiosis through information sharing and connection between companies in Tianjin. With increased transparency and data access also comes an opportunity for the research community to help reveal effective and transferrable policy insights using methods in footprint analysis, dynamic coupled systems, city and supply chain network science, and mixed methods approaches.

Opportunities for MURs to lead, or participate, in transboundary stakeholder engagement are linked to the fact that MURs are unique urban units in that they are multi-jurisdictional and polycentric, and therefore the interactions and collaborations between stakeholders required to govern the MUR-PCS intersection are inherently transboundary. Stakeholder collaboration may be facilitated by boundary organizations that do work between businesses in the global PCS and other stakeholders, however national and local governments and the private sector also appear to be required for successful sustainability action to be achieved.

The importance of each stakeholder in the cases we highlight varied depending on the role of the MUR. Boundary organizations, for instance, were central in the producer, and also consumer cases. Both Eco-TEDA in Tianjin, and Greater London Authority in London, had jurisdiction within the MUR and was seeking to mitigate the local impact of production or consumption activity. Each also had a specific objective to facilitate system efficiency that was outside the purview of other stakeholders. Emerging efforts to better understand the incentives and strategies of actors participating in such governance organizations provide the basis for building additional insight into their role in achieving sustainability aims[18,39,73]. Meanwhile, in the trader case global commodity focused NGOs served as the catalyst for private sector firms to take action. Recognizing the business incentives, the private sector firms in this case adopted voluntary standards that were legitimized by national level government stakeholders and achieved a level of infiltration within the industry because of the high degree of centrality of the trader MUR in which they were located within the PCS chain. In fact, across MUR roles, while not necessarily central players, national level government stakeholders consistently provided policy incentives and targets, either actual or proposed, that encouraged other stakeholders toward action while local government stakeholders in turn, served to legitimize the boundary organizations and facilitate private sector stakeholder participation and information sharing. That transparency is critical to progress in PCS governance innovation[43].

The intersection of MURs and PCS creates issues and opportunities around social and environmental justice, accountability, and legitimacy. Access to natural resources by smallholders in the global hinterlands of MURs can be disrupted when PCS help drive changes in property rights, for example, when community forests or fishing grounds are privatized and taken over by large firms, or governments grant firms large land concessions displacing prior occupants[18,38].

Regulations and fair practices by governments with authority in the hinterlands is often the best way to secure just outcomes but can be problematic when incentives or power structures are not aligned for that to take place. Thus, pressures and regulations on firms in the investing MURs, or traders in the PCS, may have more leverage to, for example, shorten supply chains directly to producers in the hinterlands and leverage transparency incentives that benefit smallholders or collective governance entities[43]. Using standards and certification schemes, however also come with pitfalls, for example through unrealistic criteria or high relative costs for auditing which can discriminate against smallholder firms[43] as was seen in the Bangkok trader case. Governance innovations such as introducing certification for collectives or groups of smallholders and small-scale fishers have been shown to help in pilot projects and should not be overlooked as an important component in the implementation of such programs.

Environmental justice concerns arise in PCS across the lifecycle. In cases where MURs are producing goods for global PCS which generate hazardous waste streams, the burden is placed on local residents in the MUR, often in inequitable ways. The Tianjin case, however, shows that one way to reduce the local burden is to turn waste into productive resources, a solution which becomes more efficient due to the clustering properties of MURs. The governance innovations that allow London to generate electricity from local waste heat capture is another example, as it helps replace energy that historically was provided by coal-fired power stations that had huge associated health burdens on local populations.

In cases where waste generated by consumption activities in an MUR are exported to regional hinterlands with impacts on people who live and work in those locations, extended producer responsibility programs are one innovation that has been found helpful. At least for some types of commodities, the high concentration of consumers in MURs can help make such programs logistically cost-efficient. For wastes that are reusable and recyclable, awareness building about distant impacts may be an effective way to motivate more sustainable post-consumption practices as witnessed with the growth of circular economy and industrial symbiosis principles being adapted by industry[74].

The intersection between global PCSs and MURs also creates opportunities for improving the wellbeing of under-consuming urban poor by providing access to markets for lower cost food and other key goods and services. The centrality of MURs in city networks is important to such access.

Accountability is important to PCSs governance and can take different forms depending on the drivers and incentives at play including the role of the MUR and its degree of concentration, clustering, and centrality. For instance, the centrality of Bangkok as

a trade-oriented MUR means that the export-oriented seafood sector remains sensitive to pressure from international consumer markets and retailers with accountability achieved through establishing minimum standards. Conservation, human rights, and other advocacy groups are aware of the links in the PCS and strategically target particular links, for example big firms, to try and bring about behavioral change in other harder to govern parts of the chain like fishing boats. In response, key large branded firms have needed to be pro-active in managing risks to their reputation; one way this is done is through collaborating on minimum and voluntary standards. Accountability relations among layer governments are also important, with the London case exemplifying the tensions between national and local policies and actions[18,38,73].

Strategies are needed to improve accountability by making visible the extraction of resources and disposal of wastes into distant, diffuse, global hinterlands[43]. One option is to shorten links, as done in the Tianjin and London cases through boundary work that identifies local resources in nearby waste streams. Food-shed studies help identify if and how regions might be able to feed themselves and whether localizing strategies are plausible[22,45]. Another option is to label links, as done in the Bangkok case, by government and third parties, with information on hinterland impacts. Voluntary standards and certification schemes have substantial potential for certain products even when used mostly in business-to-business exchanges[40,43]. Shortened and labeled flows are important for sustainability of PCS, and MURs may be able to take modest actions to influence these flows as they pass through their nodes by requiring such information to be attached.

Finally, MURs have opportunities to develop drivers and incentives for sustainability in PCS. As suggested by prior literature, catalysts for change and incentives for participation can emerge from any level of the PCS system[43], however we suggest that either as the influencer or the influenced, the role of MURs in those chains is uniquely important. International agreements or cooperation, and national policies such as climate change targets[49] and circular economy mandates[56,69] can be important drivers of MUR actions in PCS. The impact of that action, however, is not felt only in the MUR itself, but also, and significantly, in the global hinterlands as a result of the concentration and centrality of the MUR to the global PCS. Consumers and civil society organizations can also be drivers for more sustainable action within a PCS. Consumers may, for example, support standards or other initiatives that influence the behavior of suppliers in the hinterlands or shorten the length of supply chains[25]. While effective in forcing change in the PCS, the incentives for firms to participate may also be weak as exemplified in the trader MUR example. In that case, the centrality of the MUR as a trader in the PCS chain, nevertheless resulted in the adoption of voluntary standards.

Economic incentives including market access, lowered costs, new revenue streams and reputational risk, are significant drivers of firm behavior in PCSs and in each of the example cases. With boundary organization support, firms in the producer MUR were able to recognize efficiencies by shortening their supply chains. Similarly, in the consumer MUR, the boundary organization was created to realize revenue from local waste heat capture. In each case, an entity was created with incentive to address an externality of the PCS within the MUR.

Attention to the source and governance of drivers and incentives is required to mature pilot projects with promising technologies into sustained programs. This is particularly true for projects that require boundary organization or technical support to accomplish. In the trader role, the case study presented here suggests that an MUR may be restricted to enabling activities, however this may not be universally true and further research is needed to understand the full potential of the role. In turn, influencing the producer role of MURs in global PCSs depends on there being sufficient incentives to make purchases within the MUR. In the Tianjin case, the challenge of continuing an initiative once the external funding for the project ended was being addressed by adapting the process to fit within existing government structures. Neo-liberal reforms towards private ownership of utilities, and large-scale technologies like smart grids, both tend to shift the locus of decision-making further away from local government authorities and may transfer the power of the consumer role for an MUR to the private sector making the Greater London experience difficult to replicate in other cities.

The four levers of change discussed above create challenges and opportunities for the intersection of MURs and PCS. Mega-city regions are significant consumers of resources from local and global hinterlands, and concentrate environmental pollution and waste from PCS activities. The three cases explored here highlight the potential, but also some of the challenges and complexity involved, in introducing governance innovations to influence the MUR-PCS intersection to improve sustainability. First, success appears to require the support of different levels of government and the private sector, depending on the MUR role in the PCS. Second, moving from pilot projects with promising technologies to sustained programs requires attention to the source and governance of incentives. Third, strategies are needed to improve accountability by making visible the extraction of resources and disposal of wastes into distant, diffuse, global hinterlands.

These findings raise questions about how and to what degree an MUR and its intersecting global PCS are governable. On the one hand, mega-city region government authorities, industry associations or citizen movements, endeavor to render global PCS more governable through shaming or appeals to care, or regulations to take responsibility. On the other hand, many of those same actors simultaneously exploit the ambiguity of accountability and legitimacy relationships to secure cheaper inputs from the hinterlands, buy superior products without paying premium prices, attract industrial investments, and re-direct trade flows to generate profits. As MURs are in part the result of economic growth aspirations of higher levels of government, these regions are faced with conflicting incentives and limited capacities to adjust economic priorities on their own.

MURs have a significant role in efforts to transform global PCS in more sustainable directions, and vice-versa. The challenge is that the governance of their intersection is complex. The cases analyzed here are illustrative, and there may very well be other roles, and leverage points, for MURs to enhance their own (and others') urban sustainability through their governance influence on global PCS. Future research is needed to confirm our findings that leveraging the influence of MURs as consumers, producers and traders in global PCS requires fostering accountability, collaboration in innovation, and recognition of limits to governability by MURs alone. The accelerated pace of aggressive environmental, social & corporate governance appears to offer opportunities for novel private and public modes of governance.

Currently, our understanding of urban sustainability, multilevel governance and sustainable PCS is highly siloed. Yet the reality is that systems of governance, production, and consumption intersect in complex ways that have tangible impacts on attempts to transition to sustainable urban communities. Identifying ways that urban governance, and policy makers, can actively influence global PCS to promote sustainability opens up a range of tools that can, potentially, impact both a given MUR, but also its hinterlands, and other localities that share elements of a PCS. It may also make clear the limitations of a given MUR to influence a global PCS, and where either coalitions of actors at the urban level, or the inclusion of national and/or international actors, is required for more collaborative approaches. Research into how current policy efforts are effective in this space may lead to new approaches, or show potential pitfalls, as policy makers and

Table 2. Case specific methodology.

	Tianjin	London	Bangkok
Data sources	• Interviews • Project Data + Reports • Literature Reviews	• Interviews • Local and National Energy Databases & Reports • Local and National Energy & Climate Plans • General Media and Literature Reviews	• Interviews • Firm Reports & Press Releases • Articles • Secondary Datasets
Interviews – numbers and techniques	• Six interviews: (four Eco-TEDA staffers, one NISP, one EU Switch Asia) • Thematic, open questions	• Four interviews with international wood pellet for energy representatives, • Thematic, open questions	• 15 Interviews (import-exports firms, industry associations, retailers, government agencies, certification bodies) • Thematic, open questions
Major themes	• Program Impacts • Barriers and challenges • Future prognosis • Key actors • Role of policies and policy actors	• Barriers and challenges • Role of emergent government policies • Alliance and partnership strategy	• Meaning of sustainability • Use and value of sustainable labels • Future prospects • Who benefits most • State vs. Non-State actor roles

scholars both continue to grapple with how the growth of MURs can both challenge and catalyze transitions toward sustainability.

METHODS

Case studies

For our case studies, we selected three illustrative cases, one for each role of MURs in PCSs (producer, consumer, trader) in order to probe the conceptual framework, we developed based on the literature (see Introduction). We selected cases where there was evidence of policy interventions in a PSC with an explicit sustainability goal. Each case proceeded with slightly differentiated methodology, using a range of empirical data and semi-structured, thematic interviews to supplement other primary and secondary sources. The interviews were focused on key informants who were able to provide insights into underlying decision rationales and experiences and were used to fill in key details absent from other sources. These were meant to provide perspective in each case, as opposed to being exhaustive, especially given the relatively limited pool of possible informants in the cases.

Analytically, the research team worked inductively to extract key findings (see Discussion) from across these cases, via an iterative comparative process. Each team extracted key findings related to governance/policy, organizational considerations, and sustainability concerns (economic, social, and environmental elements). As each team shared key findings, the other teams returned to their cases to extract any similarities or differences. We then were able to consolidate the categories and findings into those found in the discussion. Please see Table 2 for specifications of methodology for each case.

Case specific methods

The Tianjin Industrial Symbiosis (IS) case study analysis was developed from a combination of IS project data, interviews, and a literature review. Qualitative interviews were conducted on three occasions with three TEDA Eco-Center staff in 2012 and a follow-up with an additional staffer in 2016.

Additional interviews were undertaken with a representative from the EU SWITCH -Asia Programme and one from the National Industrial Symbiosis Programme-UK International Synergies Ltd in 2016. All of the informants were in positions of program development, management, and/or oversight, and were able to discuss the development of the TEDA Eco-Center from initiation, with a high degree of insight, but a variety of perspectives (insider vs outsider). We were unable to secure interviews with businesses involved in the IS programs. Secondary quantitative IS project data was collected during the project period by TEDA Eco-Center, International Synergies and the EU SWITCH-Asia Programme. The Fiberweb and Toyotsu Resource Management Company synergy provided in the case study tracks the reduction of waste steel.

The interviews were focused on a number of key themes: (1) the historical process of the development of Eco-TEDA, (2) the role of the different governmental and NGOs, and/or other key actors in the process of the program's development and operations, (3) key barriers to the program's implementation, (4) factors driving success, (5) perceptions of key impacts, (6) roles policies and policy actors at different levels (municipal, provincial, national, international), (7) expected future progress and challenges.

The London case study utilized literature research, acquisition and examination of multiple government agency data sets on conventional and biobased energy fuel sources including data from the U.S. Energy Information Agency and the International Energy Agency. Interviews were conducted with producers and exporters of U.S. based wood pellets. Interviews were focused on a number of key themes including: (1) the role of emergent government policies, (2) barriers and challenges, and (3) alliance and partnership strategies in the context of existing and future policy.

The main source of new information for the Greater Bangkok Region- Fisheries Products case study was a set of 15 in-depth interviews carried out in December 2015 and January 2016 with key stakeholders involved in the certification and labeling of seafood products in Bangkok, Thailand. The informants were from: processing firms ($N = 3$), import-export firms ($N = 2$), industry associations ($N = 1$), retailers ($N = 1$), Thai government agencies ($N = 1$), certification bodies ($N = 2$), and academics/industry experts ($N = 5$). Interviews were focused on a number of key themes: (1) the meaning of sustainable and environmentally responsible, (2) the process of certification, (3) the perceived value of sustainable labels, (4) perceptions of future progress and challenges, and (5) role of policies and policy actors. Secondary data about carbon labeling of products came from the Thailand Greenhouse Gas Organization, and for fisheries products primarily from the Department of Fisheries in Thailand and FAO. CP and Thai Union also provided additional information on production and labeling.

DATA AVAILABILITY

No datasets were generated or analyzed during the current study. Energy data including exports/imports of wood pellets is available on-line from the USDA Foreign

Agricultural Service, the US Department of Energy and the International Energy Agency.

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AUTHOR CONTRIBUTIONS

All authors performed research. J.G. & E.D.-London; L.L.-Bangkok; K.M. and V.T.-Tianjin case studies. J.G., E.D., M.v.Z. and A.d.K. analyses of MUR production consumption systems. All authors contributed to the writing of the article.

COMPETING INTERESTS

The authors declare no competing interests.

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