Improving energy and material flows: a contribution to sustainability in megacities

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Abstract: As cities have become home for 50% of the world's population, urban systems have definitely caught public attention. The urban metabolism can be improved by transforming their linear behavior into a more circular one. This paper is based on a project initiated by the Division of Environmental Technology and Management at Linköping university, financed by Vinnova: *Megatech*. The aim is to study the megacities of Cairo and Mexico City in order to understand some of the problems they are facing. By improving their energy and material flows behavior, these megacities can benefit from the reduction of their dependence on fossil fuels and virgin materials; the protection of part of their social, economic and productive systems from external factors (e.g. political drawbacks, shortage/distribution problems, international prices); an increased effectiveness of their planning activities–as they would be based to a large extent on their own resources–and the reduction of their environmental burden. An *in situ* study will take place with the participation of local stakeholders. Information about environmental problems will be collected and potential solutions will be analyzed and suggested. A tentative model is presented, showing how the reinsertion of the outflows into the urban system could benefit these cities' overall environmental performance.

Keywords: *Flows analysis, Urban metabolism, Urban sustainability, Megacities.*

1. Introduction

Cities seem to be the future's structure for social and economic activities. Today, 50% of the world's population has moved into cities [1] and their uncontrolled growth has brought along problems and challenges. Some of these cities have reached once-unthinkable population levels and have been called 'megacities', after the Greek word 'mega' (μέγας – great).

These highly urbanized agglomerations concentrate people, materials, money, information and knowledge and continue to grow as more people are being attracted by the apparently endless possibilities of wealth and comfort that they offer. However, in a planet constrained by finite resources, unlimited growth is not possible [2]. Under today's circumstances, and especially given the technological and economical lock-in [3] that our societies are suffering from, most of these resources are facing short-term depletion. Nevertheless, from an industrial ecology perspective, urban agglomerations are not lacking resources–i.e. energy and materials; the problem is that important sources are being ignored or mismanaged.

Industrial ecology studies material and energy flows through different systems, with the intention of optimizing their cycles; considering them as an ecosystem, part of the biosphere surrounding it [4]. An analysis of these flows makes it possible to find options for their reinsertion into the social and economic system, while reducing the impact on t he environment and helping creating more sustainable urban settlements, where these three aspects are considered. The aim is then to propose a model describing how a better behavior of these flows–i.e. their circularization and reinsertion–reduces the environmental burden and contributes to building more sustainable societies. A description of common urban environmental challenges in two selected megacities is made, followed by a depiction of how industrial ecology can address some of them. Last, some potential results regarding energy use and CO_2 emissions reduction are shown and discussed.

2. Methodology

The *Megatech* project is an explorative research of sustainable business and clean technology markets in the megacities of Cairo and Mexico City. By using a bottom-up approach, the project's team studies these cities' dynamics from a holistic perspective, considering the social, economical and environmental spheres and analyzing their urban metabolism, aiming at detecting potential niches for Swedish CleanTech offerings.

The selection of the cities of Cairo and Mexico City was based on three criterions. The first one–as the definition of *megacity* suggests–was the population size; i.e. more than ten million inhabitants. The second criterion was the access to information, due to concerns of sufficiency and reliability. For this, strategic partners were looked at in each town in areas of interest to the project's objectives. Last, the socio-economic conditions were important for the selection, as important business opportunities can result from them. Specifically, emerging markets were of interest for the project's team, i.e. developing countries.

A case-study methodology was selected as appropriate for the analysis and understanding of the issues intended to be addressed by the project. By consulting official reports and publicly accessible information from, e.g. governmental and supra-governmental organizations, municipalities, environmental and economic councils/agencies, independent studies and local newspapers, an initial description of these settlements was developed, depicting problems and challenges from a sustainability/environmental perspective. With this information in hand, an initial identification of stakeholders gave the team an insight of the groups of interest and the indications for a first set of interviews, in order to confirm the previously acquired information, and especially in order to have the possibility of understanding these concerns from the perspective of those directly involved and affected by them. The latter would help the team build the desired bottom-up approach.

Once this information was collected and confirmed, an industrial ecology approach was used in order to analyze possible solutions for the circularization of waste flows. A tentative analysis was made by identifying sources, directions and disposal activities. Two types of results were obtained: the identification of specific problems in each town and the discussion of the benefits that could be obtained through a flow analysis and the application of the proper technologies and possible barriers and drivers for their implementation.

3. Current situation

Uncontrolled growth, both in the residential and in the industrial sector, is a big problem for megacities in developing countries. The available technical systems are not able to cope with this expansion and the increased demand of energy and waste treatment technologies are common challenges faced by their citizens and governments. More specifically, the problems detected in Cairo and Mexico City are as follows:

Cairo

Cairo has always been an important cultural, economic and commercial center of the Arab world. Such an important role has meant several challenges, embedded in the need of developing and giving its citizens a better quality of life, at the same time that it struggles to survive under the demands of a growth-addicted, competitive economic system.

The most representative environmental problems detected so far by the team are:

- *Water supply/quality.* The Egyptian culture flourished around the waters of the great Nile. However, a growing population and the political and economic demands of modern times have posed a lot of stress on this resource. Several countries share its waters and have their own development programs, which in one way or another affect Cairo–and Egypt in general, being located at the very end of its trajectory. Moreover, the high pressure on irrigation water for the production of wheat–the biggest source of protein in poor countries, thus very sensitive social-wise–is a big problem when the demand cannot be met by local resources and international prices skyrocket (see e.g. [5]). Also, wastewater treatment is not very effective, especially when more and more slum dwellers increase the burden due to their illegal and unplanned nature (see e.g. [6]).

- *Urban waste.* Solid waste is a huge problem in Cairo. The collection of waste in some areas has been outsourced to e.g. Spanish or Italian companies, who have had several problems [7, 8, 9]. Moreover, the traditional *Zabbaleen* people's activities–who make a living out of recycling or from recoverable items and by feeding their animals with the organic fraction–have been affected by the recent swine-flu paranoia, resulting in an overload of unpicked organic material on the streets [7, 10]. Despite of several efforts by the city's administration, 19 500 tons of waste produced everyday in Greater Cairo represent a huge challenge [11].

- *Traffic.* Uncontrolled traffic and air pollution are a big problem in Cairo. An average speed as low as 10 k m/h [12] reflects on higher fuel consumption and reduced productivity. In addition, industrial pollution and the natural characteristics of the region–i.e. sand blowing from the desert–add to the problems of the air's quality and public health.

- *Energy.* Fossil fuel dependency is not only a problem for the transportation and production sectors, as many families depend on them for cooking and heating purposes. It is mainly butane being distributed to households in pipes, highly subsidized by the government [13]. Shortages of this gas have caused discontent among the poorest sectors, unable to pay for higher prices [14].

- *Population.* As stated above, urban population has grown uncontrolled, especially during the last century. The last census (2006) counted around 13.5 million living in Greater Cairo [15]. Such an amount poses an enormous pressure on resources, food, housing and infrastructure in general.

Mexico City

The ancient city of *Tenochtitlán* was already an important place back in the 15th century. Today, this city lies hidden under the colossal Mexico City, which under an undoubtedly changed context, struggles to maintain its citizens' quality of life.

Today, Mexico City must face the following environmental challenges:

- *Water supply.* The level of overexploitation is estimated to be 35% [16], making the replenishment rate to be lower than needed [17] and requiring solutions that demand enormous amounts of energy, like pumping water from a 1 100-meters lower region, located 127 km away from the city [18]. In addition, the mentioned extraction has caused the underground layers to collapse, sinking infrastructure up to 40 cm in some areas [16]. Finally, several sources of pollution, both natural and artificial, harm the liquid's quality [16], causing the citizens' distrust on the quality/quantity of the water they receive [20].

- *Air.* Road transport contributes to 50% of the emissions that cause air pollution. Industry and landfills 24% and 14% respectively, followed by combustion practices in residential areas with 10% [16]. In addition, the geographic characteristics of the Valley hinder the natural dilution of these emissions. Although Mexico City has a low average PM_{10} value–around 52 μg/m^3 [19]–compared to Cairo (roughly 150 μg/m^3 [21]) or Shanghai (around 110 μg/m^3 [21]), levels have reached figures as high as 164 μg/m^3 in some areas in recent years [19].

- *Mobility.* Around 4.5 million vehicles were registered in the city by 2010 [22], with a big share of privately owned cars. In the metropolitan area, there are 397 cars/1000 people, compared to, e.g. 38 in Shanghai [23]. Speed figures are as low as 3 km/h in some places during peak hours, with an average of 21 km/h [24]. Around 20 million work-hours/day are estimated to be lost in traffic or commuting [25], due to an average daily commute time of 2.5 hours–compared to e.g. 1.4 in London [23].

- *Solid waste.* An average of 12 500 tons/day are generated in the Federal District only [16]. The landfill used has already exceeded its capacity but has not been closed due to the lack of a good alternative. Although the administration has several campaigns–e.g. waste oil collection and organic waste-sorting/handling–activities like composting or recycling are still relatively small [26].

- *Energy.* As most of the cities around the globe, Mexico City suffers from fossil fuel dependency. Mexico was the 7th oil producer in the world in 2008 [27] and petrol is cheaper than mineral water [23].

- *Population.* The Metropolitan Area of Mexico City is one of the most populated urban areas in the world, with an estimated 19.9 million inhabitants in 2009 [28], 60% of them living in illegal and informal housing [23], which means gigantic challenges for public services like drinking water, sewage and electricity.

3.1. Bending the arrows: improving the city's metabolism and finding new energy sources.

Industrial ecology looks at the conversion of linear flows into circular flows, by studying both energy and materials in a system. Urban flows are of special interest here, given the important weight that cities have on the overall environmental crisis. Although the study has not reached a mature stage yet where specific figures are available, some insights (as describe above) can help building an initial model of what is happening and how a better flows' behavior can contribute to the goal of reaching more sustainable and independent societies.

Cities are very dependent on external resources for their everyday's functioning and are normally net consumers–energy and material-wise, meaning that they have a passive role in the whole material and energetic cycle (as shown in Fig. 1).

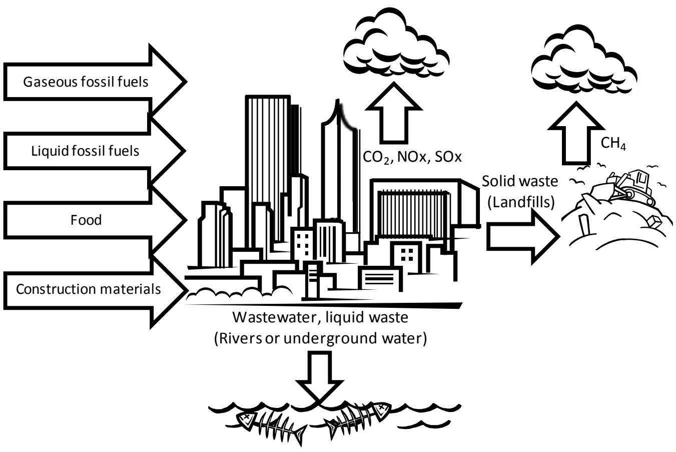

Fig. 1. All urban flows are linear and end up in natural sinks (i.e. water, air and soil).

However, environmental technology and sustainable practices have found innovative and effective solutions for most of these problems, "bending the arrows" and turning cities into more active actors, whilst reducing their environmental burden. Some examples of these solutions are:

- Urban gardening: vegetables production in green areas, roofs and urban greenhouses.
- Biogas from sewage sludge and organic waste: besides cleaning wastewater, reducing sludge volume and producing energy in the form of biogas are additional benefits. An organic fertilizer is a by-product, useful for both urban and rural agriculture.
- Waste incineration: with the proper technology, waste can be used for electrical and thermal energy production, reducing the need of landfilling and the volume of waste as much as 98%. Ashes can be used as a construction material.
- Methane capture in landfills: Landfills are a big source of methane, useful as a fuel.
- Biodiesel from used cooking oil: The collection and further processing of used oils helps reducing the pollution of water sources and the city's dependence on fossil fuels.

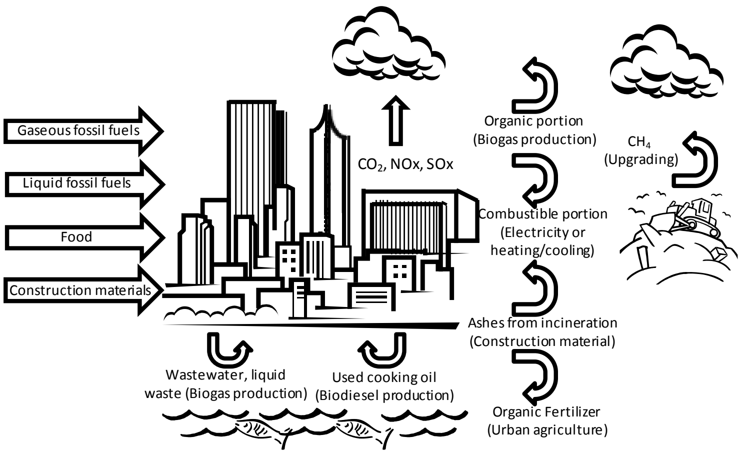

Fig. 2. By closing loops, cities improve their environmental performance.

As Fig. 2 intends to illustrate, flows entering the urban areas can be reduced, diminishing to some extent the city's necessity of external sources and protecting it against i.e. international prices, political drawbacks or unhealthy dependences. At the same time, the surrounding ecosystem is harmed to a lesser degree, manifested in the improvement of the air and water's quality and the remediation of soil.

4. Potential renewable sources and CO_2 emissions reductions

An indication of how a circularization of the urban flows could contribute partially to the solution of the energy and environmental crisis can be shown in the Mexico City's case, whilst data from Cairo is still to be collected.

A back-of-the-envelope estimation can be done regarding the potential production of biogas in the federal district, given the biological oxygen demand (BOD) content of its wastewater. Out of 118 m^3/s that were treated in 2008 in Mexico, 3.5 m^3/s (3%) are treated in the federal district [29]. Assuming that the BOD content is equally distributed all over the country (very likely to be higher given the industrial and economical activities and the population in the area), 270 300 tons BOD would be generated every year both by households and industry–out of 9 million nation-wide [29]. Each ton BOD can potentially generate 500 normal cubic meters (Nm^3) of methane by anaerobic digestion [30], meaning that around 135 MNm^3 could be produced annually only from wastewater, with an energy content of roughly 1.3 TWh/year. This is equal to the amount of energy needed by the Cutzamala system, which provides 18% of the potable water to the Valley of Mexico [29] and consumed 0.56% of the electricity produced in Mexico in 2008 [29], contributing roughly 630 000 tons CO_2 [31]. An important challenge arises considering that only 13% of Mexico City's wastewater is treated [32].

Other important sources of raw materials could back up these activities. For instance, 700 tons of organic waste are generated every day at *Central de Abastos* (wholesale market) [33], with a potential production of around 20 MNm^3 of methane/year, an energy content of 200 GWh [30] and an estimated reduction of 170 500 tons CO_2/year [33], not to mention the availability of a high-quality organic fertilizer. On the other hand, the government has plans to extract and take advantage of the methane emitted by the *Bordo Poniente* landfill, with a reduction on CO_2 emissions of roughly 1.4 million tons [33].

5. Discussion

There are technological solutions available for several of the problems that megacities suffer from, including the ones described above. However, the specific context plays a very important role if the actual feasibility of implementation was to be discussed. Social, economic and environmental factors are very variable depending on cultural, geographic and specific current conditions of the city being analyzed, reflected on ba rriers and drivers, enablers and challenges. For example, the importance of the informal economy both in Cairo and Mexico can become a ch allenge, especially when approaching the problem of waste management. Hundreds of people rely on the picking of sellable material from the collected waste both in official and parallel markets (e.g. *Zabbaleen* in Cairo and *Pepenadores* in Mexico City). Some powerful unions have been created, influencing greatly political decisions. Any attempt to modify the current situation would affect a lot of people if they are not taken into account in an integral plan that considers actions in order to keep–at least–the current income level of those doing the job and confront in an effective way the problem of illegal activities in the sector.

Another big barrier faced regarding waste management is sorting. In Mexico, for example, 43% [16] of the waste landfilled is organic and the situation in Cairo has gotten worse since pigs are not there anymore to take care of this fraction. Although there are some plans for the proper treatment of this type of waste, no significant activities are taking place currently. Regarding fuels, for example, the low prices of fossil fuels–due to subsidies–and the widely spread use of private transportation, creates a lot of economic disincentives for the production of biofuels from wastewater, used oil or organic waste. The high subsidies that governments pose on these energy carriers and the important position that oil has on t heir respective country's economy put concerns on a very low level in the ladder of priorities.

Last, the socio-economic situation of developing countries represents a very big barrier for a lot of these technologies. Some of them require huge investments–unreachable for most of them–and long pay-back periods, thus long-term commitments: sometimes too long to be considered.

Nevertheless, governments are conscious of their role in creating a b etter environment for their citizens and the generations to come. They are aware of the huge opportunities that all these challenges represent and how much international interest they attract. Programs encouraging the use of solar power for heating purposes, landfill gas capture and use and energy efficiency measures in Mexico and the construction of concentrated solar thermal power plants and wind farms in Egypt are a proof of their commitment.

Acknowledgments

This project is financed by the Swedish governmental agency for innovation systems–VINNOVA–and is being performed at the division of environmental technology and management at Linköping's university.

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