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THE ECOLOGICAL TRANSITION OF CITIES

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Abstract

The ecological transition of cities is crucial for the ecological transition of the entire world. This transition goes through the transformation of the current linear urban metabolism into a circular metabolism that mimics the functioning of ecosystems. A metabolism aiming to the minimisation of material inputs (products, water, food) in order to minimise both the withdrawal of resources from the environment and waste production. This goal can be achieved by adopting the principles of the circular economy, maximising the use of renewable sources and energy efficiency, and redesigning urban services, such as mobility and water-and-waste cycles.
In order to bring about this transformation, it is not enough to work on technologies and techniques because citizens' behaviour, lifestyles and cultural values are affected. Furthermore, treating the city as a living organism, i.e., as a complex system, requires an appropriate design and governance method underpinned by a systemic vision.

Keywords

Circular economy, Complex systems, Renewable energy, Planetary boundaries, Sustainable urban development.

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1. BACKGROUND

In 1950, only 30% of the world's population lived in cities, meaning by "city" an inhabited centre ranging from the biggest megacity to the smallest town. By 2020, the share of the urban population increased to 56.2%, and it is projected to reach 68.4% in 2050; in developed countries, people live already mostly in settlements (79.2%), while a lower share (51.6%) of developing countries inhabitants, including China, is urbanised [1].

Moreover, cities generate 85% of global GDP (Gross Domestic Product); they consume 75% of the natural resources entering the economic circuit, produce 50% of all waste, are responsible for 60-80% of greenhouse gas emissions (GHG) [2], consume 67% of all the food produced in the world [3], and it is estimated that by 2050 they will consume 80% [4]. Therefore, attention must be focused on cities because they catalyse most of the resources and economic activities and are the primary cause of environmental degradation. However, they are also innovation centres and can/should lead the way towards an environmentally and socially sustainable society.

Cities will grow mainly in developing countries, where they will require enormous amounts of resources for building up their infrastructures, from buildings to roads, and energy for their operation. At the same time, cities' growth will challenge the ecosystems, as urbanisation is also connected to the degradation and loss of forests, grassland, and marine areas (it is estimated that

90% of the wastewater in developing countries is discharged directly into waterbodies) [5].

2. CITIES' IMPACT ON GLOBAL ENVIRONMENT INTEGRITY

The current narrative on ecological transition is focused on the energy transition because of the more and more evident effects of climate change. This is a good starting point, but climate change is only one of the environmental problems we must solve, as shown in 2009 by a group of Earth system and environmental scientists [6]. They identified nine processes regulating the stability and resilience of the Earth system that we must keep under control and the nine limits that we must not transgress for maintaining planet Earth in the conditions that allowed the human civilisation and within which humanity can continue to develop and thrive for generations to come (Fig. 1). Crossing these boundaries increases the risk of generating large-scale abrupt, or irreversible environmental changes.

The nine planetary boundaries identified are:

1. Climate Change; caused mainly by the alteration of the CO_2 cycle through the increase in its concentration in the atmosphere. Other gases also contribute: methane, nitrogen oxides and fluorinated gases;
2. Chemical Pollution and the release of novel entities; namely radioactive compounds, heavy metals and a wide range of artificial chemical compounds and biological organisms;
3. Stratospheric Ozone Depletion; caused by human actions (emissions of CFCs, i.e., chlorofluorocarbons and nitrogen oxides);
4. Atmospheric Aerosol Loading; affecting the climate system and having adverse effects on health. It is mainly caused by burning fossil fuels and wildfires;
5. Ocean Acidification; caused mainly by the increase of CO_2 in the atmosphere dissolving in water;

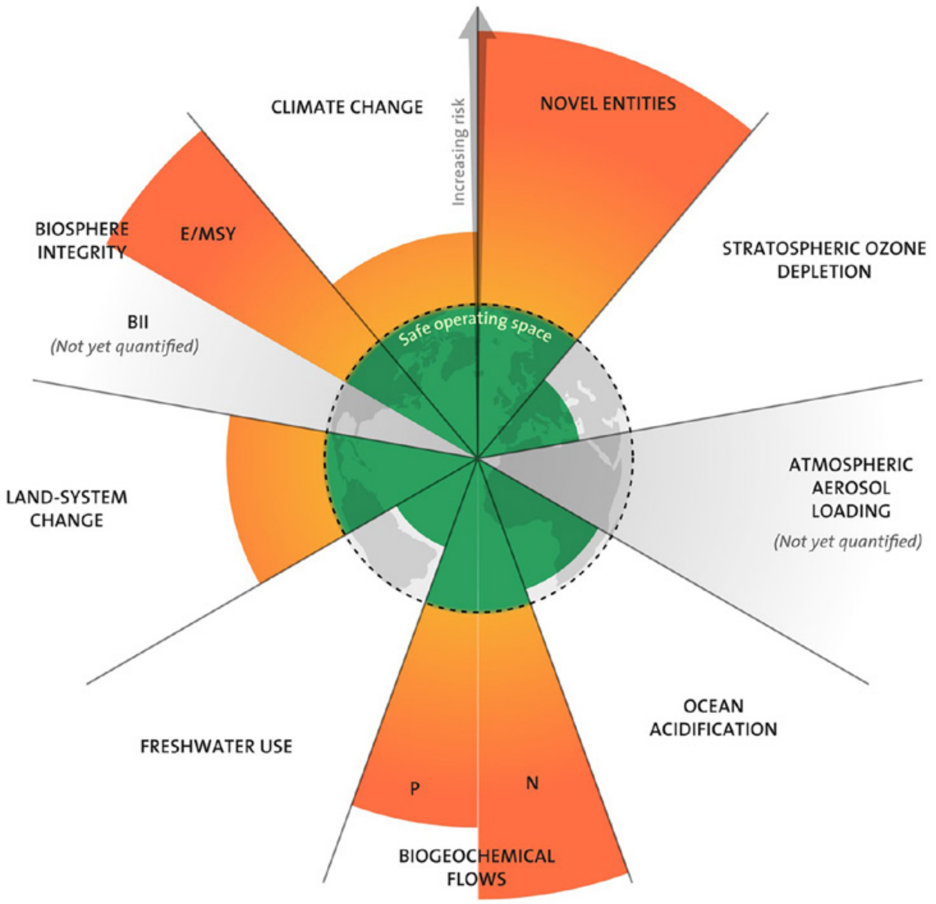

Fig. 1. *Planetary Boundaries [9].*

6. Nitrogen and Phosphorus Flows to land, water bodies and oceans; due mainly to the continuous input into the agricultural production system of large quantities of artificial nitrogen compounds and phosphates extracted from mines;
7. Freshwater Consumption; which has altered the Earth's hydrological cycle through the often senseless use of water resources in agriculture, above all, but also in industry and urban centres;
8. Land System Change; such as deforestation to create arable land, the transformation of wetlands into fish farms and grasslands into plantations, the expansion of cities, and the construction of transport infrastructure;
9. Loss of Biosphere Integrity; biodiversity loss and extinctions.

These nine processes are mutually interconnected and are all affected by urban resource consumption, which is also the main direct and indirect cause of some of their limits being exceeded.

The importance of the link between cities and the exceeding of planetary limits, i.e., between urban metabolism and the high risk of triggering catastrophic processes that will spare no one, is highlighted by the fact that limits have already been exceeded for the following five processes [7, 8]:

- climate change; cities contribute more than two-thirds of climate-changing gas emissions;
- modification of the biogeochemical cycle of nitrogen and phosphorus, primarily caused by food production, of which cities are the main consumers, and by not treated wastewater discharge;
- changes in land use, also mainly due to food production and by cities growth;
- novel entities, due to excess urban waste, food production and industrial chemicals pollution
- the loss of biosphere integrity, mainly caused by exceeding the four limits above and the pressure on the other four.

3. THE URBAN METABOLISM

«The notion of urban metabolism is loosely based on an analogy with the metabolism of organisms, although in other respects, parallels can also be made between cities and ecosystems. Cities are similar to organisms in that they consume resources from their surroundings and excrete wastes» [10].

The resources consumed are flows of materials, food, water and energy; once metabolised, these flows turn into waste, which is expelled in the form of greenhouse gases, wastewater, organic and inorganic solid waste, and low-temperature heat (Fig. 2).

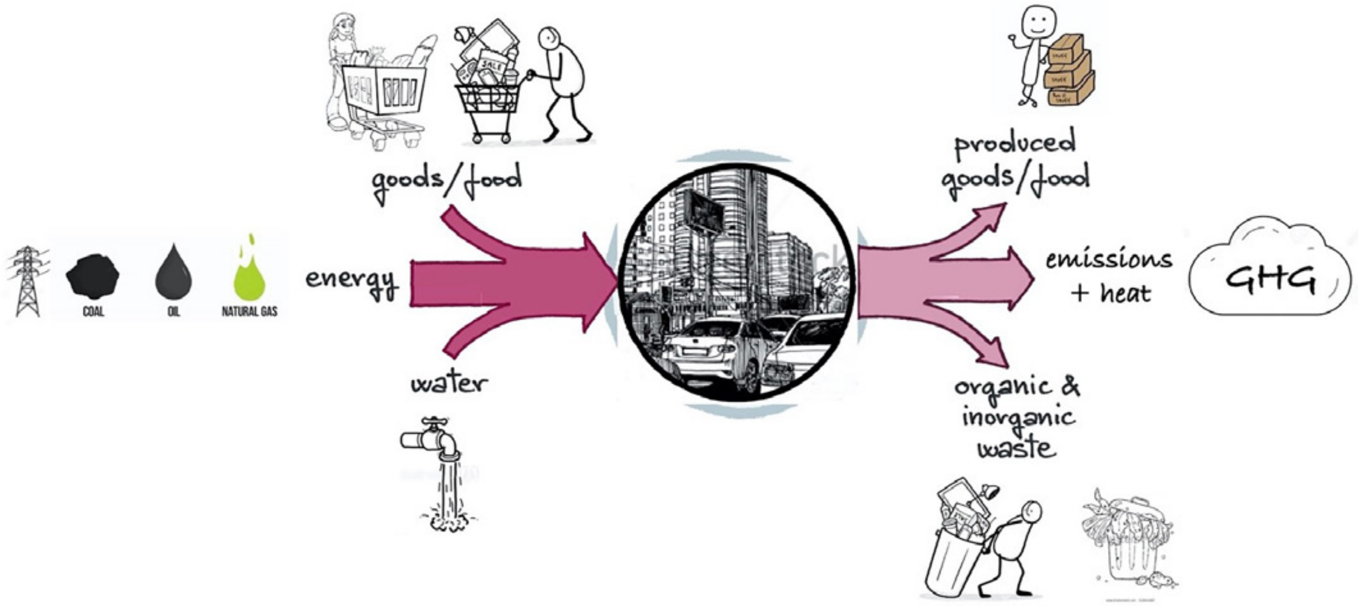

Fig. 2. *The urban metabolism.*

The metabolism of today's settlements is generally linear, i.e., the inputs crossing their borders are distributed inside the settlement and used to keep all the functions working; after their use, they are disposed of as waste outside the borders. In this model, the development and growth of the settlements are accompanied by a corresponding increase of inputs and, consequently, of waste, with increasing pressure on the environment's integrity. The linear "Take - Make - Dispose" lifestyle increasingly depletes finite natural reserves producing wastes in quantities that the environment is not capable of absorbing without damage.

3.1. ENERGY AND MATERIAL FLOW

People usually connect GHG emissions with energy consumption and are quite aware of the fact that heating and cooling buildings, lighting a room, heating water, driving a vehicle, etc., implies CO_2 emissions. For this reason, people – and policymakers – generally think that the problem of global warming can be solved simply by substituting the fossil fuel flow entering the city with a renewable energy flow.

Thus, the method used for the emissions inventory of a settlement is usually "production-based". This method captures GHG emissions associated with all significant urban activities within physical city boundaries, i.e., transport, buildings and industries, agriculture, forestry and other land uses (where applicable), as well as waste disposal and wastewater treatment. Emissions due to the production of the electricity consumed in the settlement are also accounted for, even if the production occurs in a power station outside the settlement's borders.

However, this accounting framework does not fully reflect the impact that cities have on global emissions, as it does not take into consideration the emissions associated with goods and services consumed in the city but produced elsewhere.

A consumption-based accounting framework should be used to include the climate impact of goods and services consumed in cities. This framework allocates all GHG emissions associated with the production and distribution of goods and services to the final consumer, allowing for the total GHG emissions associated with city residents and, by association, the businesses and institutional activities serving them.

The consumption-based approach captures both direct and lifecycle GHG emissions of goods and services (including those from raw materials, manufacture, distribution, retail and disposal), and allocates GHG emissions to the final consumers of those goods and services rather than to the original producers of those GHG emissions. GHG emissions from visitor activities and the production of goods and services within the city boundary that are exported for consumption outside the city boundary are excluded.

In simple terms, a consumption-based GHG inventory can be defined as the emissions arising within a city's boundaries (production-based emissions) minus those emissions associated with the production of goods and services exported to meet demand outside the city, plus emissions arising in supply chains for goods and services produced outside the city but imported for consumption by its residents, the so-called embodied emissions.

To give an idea of the gap between the two accounting frameworks, an evaluation [11] carried out for the C40 cities (a network of the world's megacities committed to addressing climate change) shows that 85% of emissions associated with goods and services consumed in C40 cities are imported from elsewhere (including electricity) and only 15% produced within their borders.

From the consumption-based approach, the set of actions to implement for minimising or zeroing the settlements' GHG emissions can be derived, starting from the evidence that there are two emission sources to consider, the produced ones and those embodied in the goods, services and food imported.

On the other hand, any product is not only the cause of greenhouse gas emissions, i.e., it has a carbon footprint, but it also has a water footprint (the water used for its production). Any product is also the cause of aerosol emissions (which affect the global climate, as well as being harmful to health), and, in many cases, it is the cause of the release of novel entities into the environment (the chemicals used in the production process, plastics, etc.); it is also indirectly the cause of ocean acidification and, through the extraction of raw materials and the cities growth, is a cause of land use change. Suppose we focus on agricultural products, which are a non-negligible part of the flow of matter feeding the urban metabolism. In that case, we see that they have a tremendous impact on the planetary boundaries' transgression. This is because food production, in addition to contributing 24% to global greenhouse gas emissions and being the leading cause of the overshooting of three planetary limits (biogeochemical flows, land use change and biodiversity loss), also has a heavy impact on the global use of water and is a significant cause of the introduction of new entities (herbicides, insecticides, fungicides, antibiotics, hormones, etc.).

We may conclude that the flow of goods entering the cities is the main cause of their impact on planetary boundaries and, given their weight on global environmental degradation, this flow is the first responsible for the present planet's sickness.

4. REDESIGNING THE URBAN METABOLISM

To reduce the cities' impact on the environment, a new metabolism model is needed to simultaneously lower resource consumption, i.e., material input, and waste production. A metabolism which tries to mimic the way ecosystems work, where it is always the same amount of matter circulating, used and reused an infinite number of times, the cycle being powered by solar energy, and where the concept of waste does not exist. Key issues to be addressed in a different way are: consumed emissions, goods, water and nutrient flows.

4.1. MINIMISE CONSUMED EMISSIONS

The large majority of buildings nowadays use power for lighting, electric appliances and all the electronic devices our houses are full of. The power demand of buildings has been growing in the last few years, especially for the growing number of electric and electronic equipment. Despite this growth, however, in temperate climates buildings, the largest share of energy consumption has been due to fossil fuel combustion to provide space heating and hot water. In order to achieve the net zero emissions goal, there is broad consensus on the need for also electrifying space heating and hot water production by means of heat pumps instead of gas or oil boilers. This choice is obliged, as zero-emissions electricity can be produced using PV panels and wind turbines, and heat pumps are the most efficient technology for providing the services requested.

Buildings' roofs can host PV panels, transforming households from power consumers into power prosumers, as they also produce electricity. Moreover, buildings host, more and more frequently, electricity storage systems, i.e., batteries, that can be shared among a few prosumers mutually interconnected to build up an energy community. A sustainable city is made of renewable energy communities.

Then, there is the issue of building materials' embodied emissions. An issue that will be more and more important as the energy needed by buildings operation will be renewable. In the very end, if renewables fully provide the building's operation energy, the only emissions are the embedded ones, and materials like cement and steel, which have very high embodied emissions, must be used carefully.

The global environmental impact of the materials' use in buildings is very high: it is estimated that 46% of the world building stock in 2050 will have been built between 2015, i.e., the world building stock in 2050 will have almost doubled [12].

Thus, the main issue for architects designing present and future buildings is the choice of materials, looking for the least impactful. This objective requires the development of new materials and the wise use of existing, low-emission materials. New building regulations will be necessary to make the use of low-emission materials mandatory. There is already a growing variety of low-emission and low-environmental impact new materials and components, but the problem is to have their environmental performances certified. At the same time, learning to reuse the building material resulting from excavation and demolition is essential instead of sending it to a landfill.

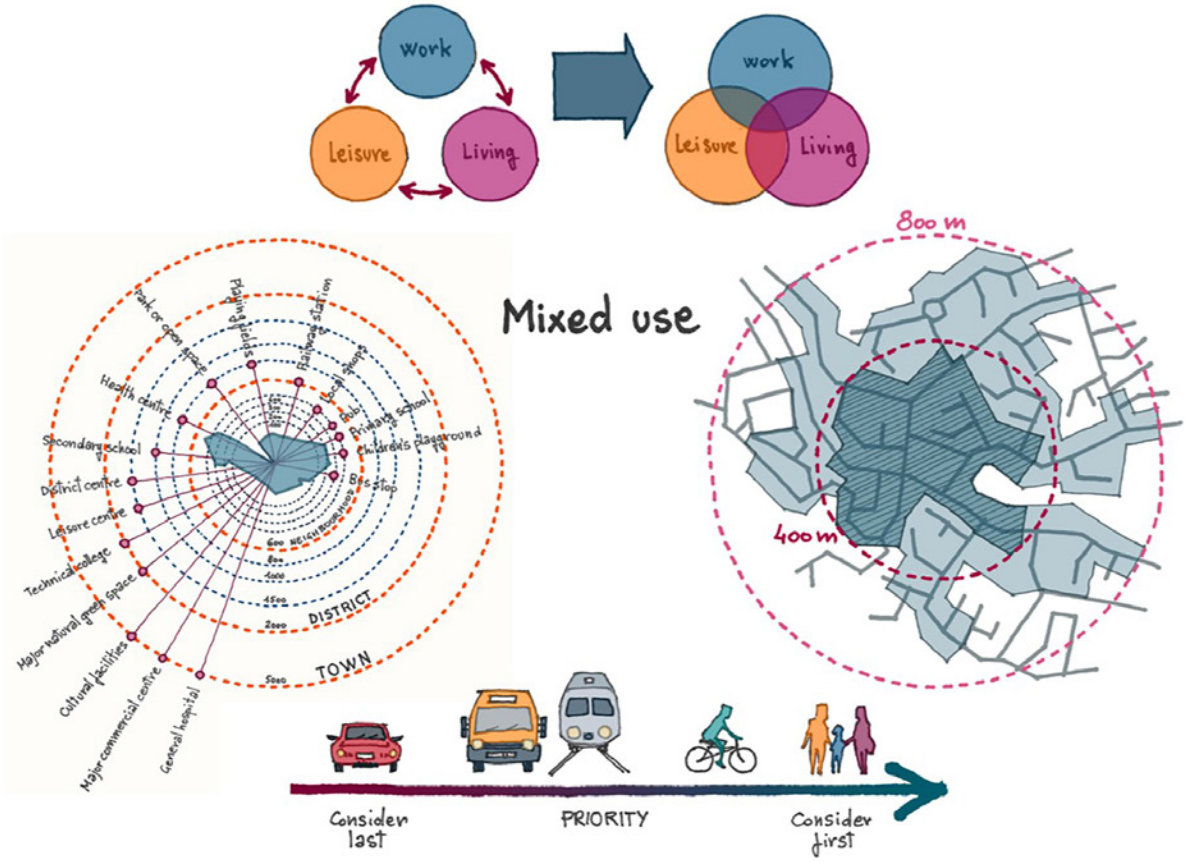

Fig. 3. *Five minutes' walk strategy.*

The way a neighbourhood is conceived has a substantial indirect impact on GHG emissions due to motorised transport. In fact, building and neighbourhood design is also connected with mobility in many ways. The main connection is related to the 5 minutes' walk strategy (Fig. 3), which is based on the idea that all the places a citizen needs to reach with high frequency are within a maximum 5-10 minutes walk from home (the best is 5 minutes, according to sustainable urban planning literature; Paris, instead, is implementing the 15 minutes city approach). These places are those related to education, work, knowledge exchange, shopping, recreation, community engagement, health, public transport, exercise, and nutrition. This approach is the so-called mixed land use, opposite to the one based on the spatial separation of main urban functions (work, living, leisure) that has been driving 20th-century urban development.

The implementation of such a strategy reduces so much the need for a car that most citizens will give up theirs and will move to walk or ride a bicycle – and use car-sharing services when occasionally the car is unavoidable. In this vision, vehicles are electric and powered by renewable energy.

The connection between neighbourhoods' design and GHG emissions is further reinforced by the fact that by making car ownership useless in most cases, the number of cars would significantly be reduced, accordingly reducing the amount of embodied emissions, as new vehicles would not be built.

Buildings and mobility will be more intertwined with the growth of electric cars, as their battery can be used as electricity storage for a single building or as distributed storage for the grid.

4.2. THE CIRCULAR ECONOMY MODEL

The adoption of the concept of circular economy is crucial. The transition to a circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, should be the driving principle in the design of a city in order to be sustainable (Fig. 4).

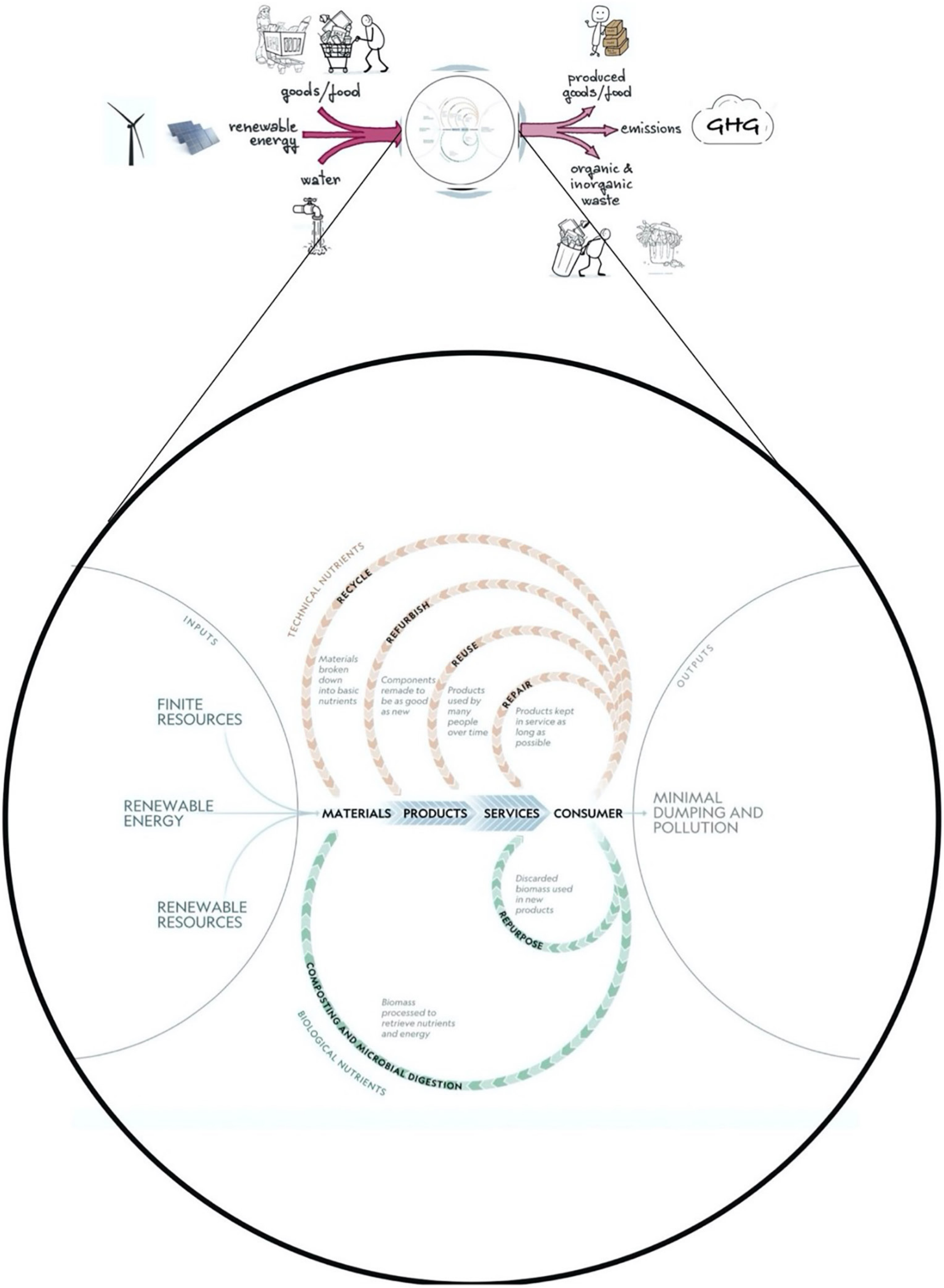

Fig. 4. *Circular metabolism (adapted from National Geographic, https://www.nationalgeographic.com/magazine/article/how-a-circular-economy-could-save-the-world-feature).*

Circular economy pillars are, among others [13]:

- improving product durability, reusability, upgradability and reparability... and increasing their energy and resource efficiency;
- increasing recycled content in products while ensuring their performance and safety;
- enabling remanufacturing and high-quality recycling;
- reducing carbon and environmental footprints;
- restricting single-use and countering premature obsolescence;
- introducing a ban on the destruction of unsold durable goods;
- incentivising product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its lifecycle.

It is a sort of revolution. It involves a shift from a production-based economy to a mixed economy, in which production is strongly reduced, and maintenance is increased. It also changes the labour market, offering great potential for new activities and jobs.

The effects of circular economy adoption are multiple. One is the reduction of the consumed emissions, as the amount of goods entering the city is strongly reduced, along with the flow of embodied emissions. Another effect is reducing the amount of material extracted from the environment, with consequent lesser impact on ecosystems, water and land use, and novel entities pollution. But the most revolutionary effect is on our economic system. Indeed the basis on which it is presently built, consumerism and the unlimited growth of the production of goods and services, is seriously challenged, as well as the unlimited growth of GDP.

Our addiction to the current lifestyle is seriously challenged, based on a compulsive need to consume, induced by a prevailing culture in which the more you have, the better you are. Circular economy adoption implies restoring an old and forgotten value: sobriety.

4.2.1. CIRCULAR ECONOMY APPLIED TO WATER

We must view water as part of a circular economy, in which it retains full value after each use and eventually returns to the system: a system in which water circulates in closed loops, allowing repeated use. Sustainable water management embraces the following:

- conservation of water sources;
- use of multiple water sources, including rainwater harvesting, stormwater management and wastewater reuse;
- treatment of water to the extent it is needed, exploiting the energy that wastewater can produce for the benefit of the settlement and the nutrient potential of wastewater for the benefit of urban and peri-urban agriculture.

Water, in cities, is not only a crucial issue in terms of environmental impact but is also crucial as a cause of damage to cities' activities and infrastructures because of the more and more frequent excessive precipitation and consequent flooding.

Thus, water is a critical issue also in terms of adaptation to the effects of climate change.

4.2.1.1. Rainwater harvesting

Rainwater harvesting can reduce pressures on rivers, lakes, and other water sources and help prevent urban flooding by reducing storm flows. It should be considered for non-potable uses.

In the new perspective of ecological transition and of many decades of altered climate, rainwater must be considered in designing new urban developments.

4.2.1.2. Decentralised wastewater management

Wastewater produced by households is usually subdivided into black water, grey water and stormwater. Black water is the wastewater from the toilet and kitchen sink; grey water consists of the wastewater from washing/bathing and washing clothes.

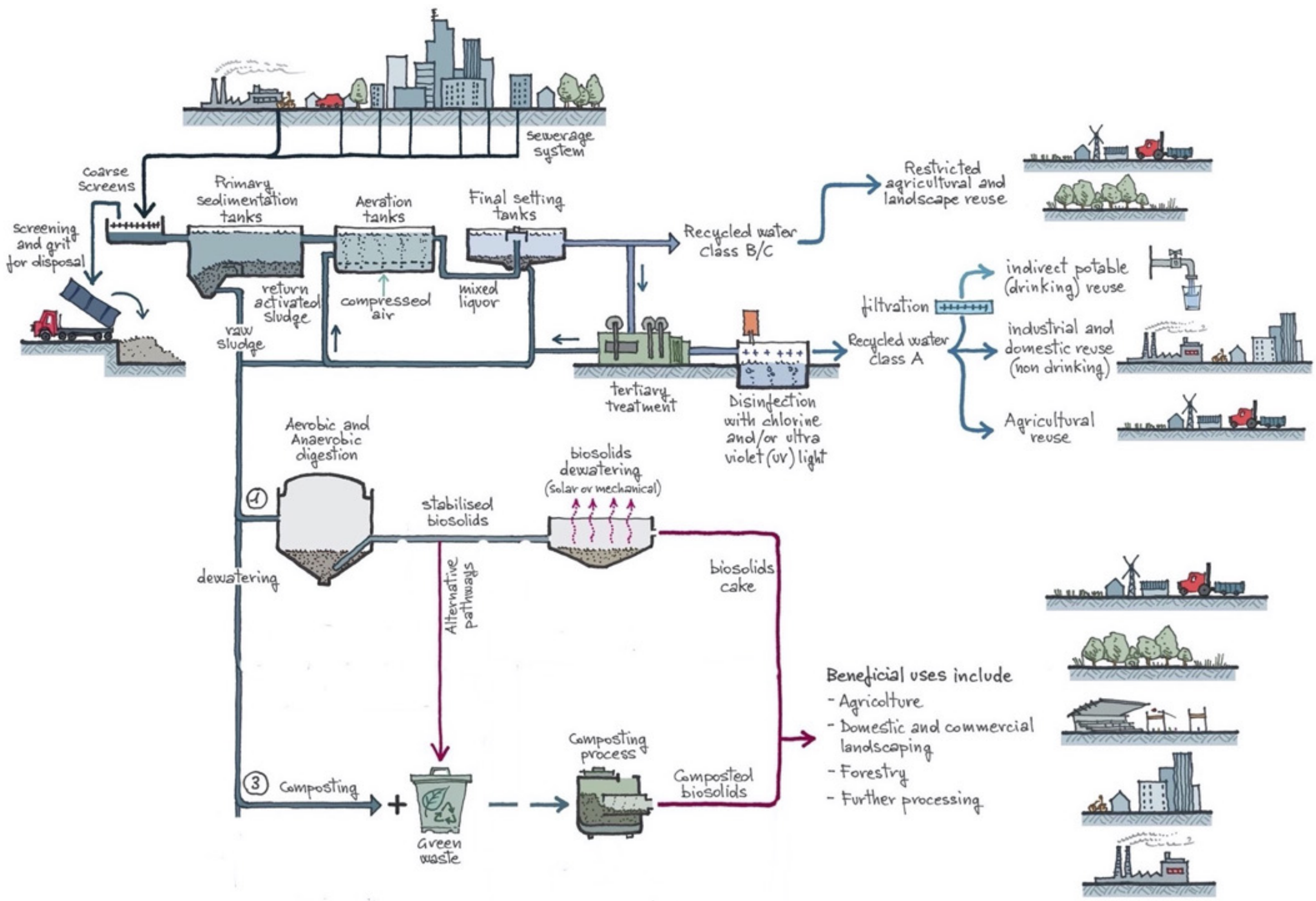

Fig. 5. *Wastewater treatment.*

What usually happens is that the three water sources are all conveyed to the sewage, mixed, and then sent to the centralised wastewater plant. It would be far better to collect rainwater separately and treat grey water locally, as it requires a simple process because of its low level of contamination, reusing it locally for non-potable uses such as toilet flushing, laundry washing, plant watering, etc. The reuse of rain and grey water can potentially reduce the demand for water supply from outside, more or less faraway sources, and reduce both the carbon and the water footprint of water services.

On the other hand, reusing grey water and/or the direct use of rainwater requires dedicated piping other than the usual one for potable water.

The treatment of black water, mixed or not with grey water, is a more complex issue because of health hazard implications. The current trend is to centralise the treatment system.

Wastewater treatment plants are based on biological processes. The treatment can be carried out either in the presence of oxygen (aerobic system) or in its absence (anaerobic system). At the end of the process, we have a flow of clean water that can be used for irrigation, a flow of sludge that can be used as fertiliser, plus, in the case of the anaerobic system, a flow of biogas (Fig. 5).

Unfortunately, both treated water and sludge are very often not reused, but wasted by, respectively, pouring it into water bodies and sending the dried sludge to the landfill or incineration.

Biogas production is rare in cities' treatment plants, even if the benefits of anaerobic digestion of sewage sludge are widely recognised, and the technology is well established.

4.2.2. CIRCULAR ECONOMY APPLIED TO SOLID WASTE

According to the principles of the circular economy, the first action in solid waste management should be a reduction in the inflow of goods, which is the primary cause of the waste flow.

For example, packaging can be reduced by encouraging the sale of unpackaged products; reuse can be facilitated by implementing a deposit return scheme for bottles and cans; the repair of appliances and clothing can be encouraged in several ways; single-use goods can be banned or discouraged; and so on.

In such a city, the amount of inorganic solid waste would be significantly reduced. It would be separated at origin (i.e. by citizens before their collection) into the main types, such as glass, metals, paper, and others, and then sent for recycling.

The first priority in reducing organic waste is reducing food waste. This action requires two combined efforts:

- reduction of the excess food purchased, which implies behavioural change;
- increase the number of proximity shops where food can be bought every day, instead of driving to a supermarket every week, which implies using the car and often purchasing more food than needed.

After measures have been taken to reduce organic waste, this should be introduced into the nutrient cycle and exploited for its energy potential.

The best is to use food waste to feed an anaerobic digester, thus producing biogas and a slurry that can be used as fertiliser directly or after appropriate processing.

To complete the closure of the city's organic waste cycle, branches from tree pruning could feed a gasifier, also producing biochar which can be used as a soil improver.

4.2.3. CIRCULAR ECONOMY AND REGENERATIVE AGRICULTURE

Circular economy adoption implies restoring the nutrients cycle, the cycle of all those substances contained in the food we eat that are essential to our physical well-being and health. At the world scale, only a tiny fraction (2%) [3] of nutrients in the food, which are then contained in our excreta, return to the soil from which they came. These nutrients are lost and replaced with artificial fertilisers. Hence the need not only for a different treatment process of black water and food waste but also for a new close input-output interaction between settlements and the surrounding rural areas. But this is not enough, as the way food is produced must also be changed.

Cities can significantly influence the way food is grown, particularly by interacting with producers in their peri-urban and rural surroundings. Regenerative approaches to food production will ensure the food entering cities is cultivated in a way that enhances rather than degrades the environment and creates many other systemic benefits, such as protecting our health.

Examples of regenerative practices include shifting from synthetic to organic fertilisers, employing crop rotation, and using greater crop variation to promote biodiversity.

Regenerative practices support the development of healthy soils, which can result in foods with improved taste and micronutrient content. Cites cannot, of course, implement these techniques alone. Collaborating with farmers, and rewarding them for adopting these beneficial approaches, will be essential.

Cities can source a large share of food from their surrounding areas: 40% of the world's cropland is located within a 20 km radius around urban boundaries [3]. Cities can use their demand power to influence peri-urban farmers to adopt more regenerative practices and, at the same time, return nutrients to peri-urban farms in the form of organic fertilisers derived from urban food waste and wastewater.

While local sourcing is not a silver bullet, reconnecting cities with their local food production supports the development of a distributed and regenerative agricultural system. It allows cities to increase the resilience of their food supply by relying on a more diverse range of suppliers (local and global) and supporting native crop varieties. It allows city dwellers to strengthen their connection with food and the farmers who grow it, often increasing the likelihood that people will demand food grown using regenerative practices that benefit the local environment and their health. Local sourcing can also reduce the need for excess packaging and shorten distribution supply chains.

5. GOVERNANCE OF THE URBAN TRANSITION TO SUSTAINABILITY

It has been shown that the most effective approach for driving a settlement along the sustainability path involves several actions covering a large spectrum of issues, ranging from energy production to flood prevention, from mobility to waste management. Not only are technological changes needed, but also the way city life is organised must change, as the circular economy requires. Citizens' lifestyles must change, changing the values that move their actions, cultural values that are intangible but crucial factors in the difficult path to sustainability: no more consumerism, but sobriety, reflecting the principle of sufficiency. Less competition and more cooperation. Solidarity and, precondition of the ecological transition, less inequality.

All these items, and the technical/technological ones, are tightly interconnected: we must be aware that the city is a complex system. This knowledge implies a methodological change in the planning approach.

The usual approach has been the one developed within a reductionistic view of reality: there is a problem, let's split it into parts, analyse each piece and try to optimise it, with the belief that if each part is working properly, also the entire system will perform at best. This approach is intrinsically wrong because in a complex system, as a settlement is, problems must be faced with a system approach, highlighting the crucial role of the interconnections between the subsystems. Interconnections that are not always explicit at a first analysis may become evident as a consequence of new actions that alter the previous status of the system. With the ecological transition, something new has to be faced: the city we want to realise is profoundly different from the present one, and we do not have examples to refer to. This evidence, coupled with the need for a system approach, requires the adoption of a planning methodology different from the usual one, such as backcasting.

Backcasting is a planning method that starts with defining a desirable future and then works backwards to identify policies and programs that will connect that specified future to the present.

While forecasting involves predicting the future based on current trend analysis, backcasting approaches the challenge of discussing the future from the opposite direction. It is a method in which the desired future conditions are envisioned, and steps are then defined to attain those conditions rather than taking actions that are merely a continuation of present methods extrapolated into the future. Thus, once the long-term vision is agreed upon among all the stakeholders (citizens, institutions, entrepreneurs, etc.), each action implies checking both the feasibility in the present and the compatibility with the vision of the future. This process will not be linear or straightforward, being the city a complex system, but will follow an adaptive path, similar to steering a sailing boat: you start from a port and want to reach another port, but you cannot go there straight, because your route depends on wind, currents, waves, the type of boat and the skill of the skipper. Sometimes you may have to go very far from the target port or even go backwards or stop temporarily in another harbour. When you sail towards the selected port, it is also possible that something has changed inside the boat o in the originally desired port, and a new port is chosen. And each change of direction along the journey has to be agreed upon among crew and passengers.

Not an easy task, indeed. But a challenge we have necessarily to face.

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