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The impact of climate change on cities in the context of a systemic crisis

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Major cities depend on the daily entrance and transportation of large amounts of food, water, power and other materials. And also on complex waste disposal management systems. When combined, these factors require mass mobility. These elements, which are essential to the functioning of major urban hubs, will be compromised as a result of the climate change process in the context of a progressively more global systemic crisis. This makes cities like Barcelona unsustainable and social and economic ruralisation policies essential.

1. Urban ecodependences

The 20th century saw the explosion of the metropolis in a way never seen before in history. This growth has continued into the first decades of the 21st century[1]. In the case of the Barcelona Metropolitan Area, this is reflected in its 3.3 million residents, almost 50% of Catalonia's population. As part of its growth, the city has swallowed up spaces that had been saved as part of a centuries-old dialogue between humans and nature, destroying the memory held by this territory and breaking the ties that connected the historic city to the territory, which had already been severely affected by the industrial city of the 19th century. Furthermore, the eruption of the city has been blurred, with no defined borders, unlike the agrarian city or even the industrial city. This space, which has destroyed ecosystems and social frameworks, is now the main niche for the reproduction of capital[2]. Therefore, it represents the backbone of our socioeconomic system.

Different factors have driven this growth, but only one has made it possible: the environment. For cities to have become megalopolis, the provision of large amounts of power (electricity, fossil fuels) and materials (food, water, different goods) has been essential. Also, their ability to dispose of the huge amounts of waste that they generate has been fundamental[3].

This flow of materials and energy has had to satisfy three significant requirements: being fast, spanning large distances and facilitating the transportation of large masses. Furthermore, the

1. A graphical image of the growth of Barcelona can be found on this page: http://ajuntament.barcelona.cat/museuhistoria/cartahistorica/.
2. They generate more than 80 % of the world's GDP (World Bank, 2020).
3. In the 21st century, cities consume 78% of the world's energy and more than 75% of its natural resources in addition to generating 60% of GHGs and 70% of waste (UN-Habitat, 2012; Gardner, 2016). They demand 6 million tonnes of construction material and generate 2.6 million tonnes of waste and 200 million kilolitres of effluents (Pengue, 2017). Making a difference depends on new buildings and waste disposal sites.

movement of materials and energy is not only necessary between the city and the outside world, but also within the city itself, as the sheer size of cities has made it necessary to reproduce the same frameworks in place with the outside world, within the city itself. To this end, the urban explosion is inextricably linked to high-capacity roads (motorways, highways)[4], major airports and super ports, water supply networks, electric motorways, oil and gas pipelines and fibre optic networks. Not to mention motorised mobility: cars, lorries, ships and planes, in particular.

The approach used to manage this work is the power and material dependences of cities and how they will be affected by the systemic crisis, of which climate change is one of the most important manifestations.

2. Systemic crisis

Climate change will not only affect future generations: it is happening right now and will gradually worsen (even in the best case scenarios) in the coming decades. The path that the Earth system has taken is now unstoppable, even if we were to stop releasing greenhouse gases.

The impacts of climate change on human life are countless. One way of seeing these impacts is to monitor how global warming is already reducing, and will continue to do so, to a much greater extent in the future, the flow of materials and power required by cities to survive. For example, climate change is harming our ability to produce food, leading to greater evapotranspiration and, in the Mediterranean region, a decrease in rainfall.

The two fundamental vectors of greenhouse gas emissions are combustion, mainly hydrocarbons and the agro-industrial food model. To this end, reducing greenhouse gas emissions will inevitably require a very drastic reduction in energy consumption in general. This will affect other central elements of the urban metabolism, such as mobility, energy and available materials.

Furthermore, this reduction needs to take place very quickly (UNEP, 2019) to limit the likelihood of a series of positive feedback loops being activated. If this happens, the Earth system will take the reins to ensure that the climate evolves towards another balance of between 4 ºC and 6 ºC more and mankind will lose its ability to slow down this process. This new climate balance would mean that vast areas of land, including the Mediterranean basin, would be practically uninhabitable for mankind (Hansen *et al.*, 2017).

However, climate change is not the only environmental crisis that mankind currently faces. We are also coming to the end of the abundant and versatile availability of power offered by fossil fuels and many other elements. Added to this is the loss of mass biodiversity or, in other words, a malfunctioning of the ecosystems on which cities depend (to guarantee clean water, purify air, maintain the fertility of the soil, etc.) (Fernández Durán and González Reyes, 2018).

Faced with this major challenge, we can’t expect developments in technology to overcome the systemic crisis (Fernández Durán and González Reyes, 2018). As a result, major cities like Barcelona will gradually lose the supplies they depend on due to climate change and other contemporary environmental crises. This will make them unsustainable in the medium term.

Furthermore, a multidimensional emergency is already with us: in just the first four months of 2020, we have seen unprecedented fires in Australia (with climate change playing a role in them), an extraordinary storm (Gloria) in the Eastern region (climate change once again), a pandemic that has brought half the world to a standstill (one of the causes of which was ecosystemic disruption) and an economic crisis usually seen only once every century in the capitalist world, just twelve years after the most recent economic crisis (catalysed by the energy crisis). Therefore,

4. ALTHOUGH AT THE START OF THE 20TH CENTURY, THE RAIL NETWORK “only” encompassed the USA, Europe, India, Japan, Argentina, Mexico, with a few minor exceptions, the road network at the start of the 21st century spans almost the entire planet, with huge levels of capillarity and density.

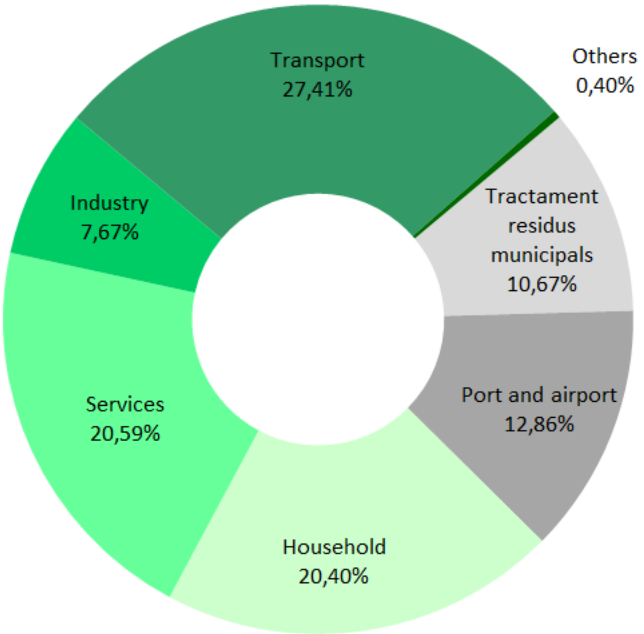
implementing adaptation and mitigation measures cannot be put off: they must be implemented on a mass scale (and fast), right now.

3. Mobility

The Barcelona Metropolitan Area spans 3,300 km² and it is home to 3.3 million residents. In this space, as is the case in all major urban hubs, the main urban functions (living, working, enjoying leisure time) have been separated, creating dedicated spaces for each function. This means that mobility within the city is very high. This is not a circumstantial problem, but a structural problem in terms of the design and size of the space.

Therefore (in addition to other factors), despite the extensive public transport network, the number of private vehicles in Barcelona comes to almost 2.5 million, with more than 800,000 mopeds and motorbikes. And as it is not just people who need to travel long distances every day, there are also almost 500,000 lorries and vans on the road (IDESCAT, 2020). The issue lies in the fact that in Barcelona, urban transport is the sector that most contributes to total emissions (Graph 1).

Graph 1. CO_{2eq} emissions per sector in Barcelona



Source: Barcelona City Council (2020)

Two of the most commonly repeated proposals in the fight against the climate emergency (and the energy emergency) are to reduce mobility and commit to sustainable transport (public transport, by bicycle, on foot, etc.). In reality, when looking at the figures of people and goods, the distances travelled and the speed required to ensure the city remains competitive, it becomes obvious that this will not be possible. Mass private transport is no coincidence in metropolises, rather a factor that allows them to exist. It is irreplaceable.

In light of this, a switch to electrified private transport is being advocated. To make the mass use of electric cars a reality, we need to boost the integration of renewable sources of energy[5] into the power grid (which would also need to be restructured to support an intermittent and decentralised supply) as must the grid connection points (of which there would need to be more than petrol stations, as the autonomy of electric vehicles is smaller); major electricity storage systems would be needed, which poses huge, unresolved technological challenges, and a huge fleet of cars

5. The electricity used by 24 million electric vehicles would add between 20% and 25% to Spanish electricity consumption. However, the power needed at charging stations would almost double the current installed capacity (Prieto, 2019).

powered by combustion engines would have to be replaced by electric cars, starting almost from scratch[6]. Furthermore, in a best case scenario, given the limited reserves of lithium, nickel and platinum, the number of electrical vehicles would be significantly lower than the current fleet of vehicles. On top of all this, in terms of the mineral value of the resources used to construct electric vehicles, 2.2 times more resources are needed than is the case for combustion vehicles (Almazán, 2018; Fernández Durán and González Reyes, 2018; Prieto, 2019).

Even if this mass electrification of the vehicles on our roads were possible (which it isn't), from a climate perspective, a significant reduction in numbers would be needed, as over the useful life of electric cars, CO_2 emissions when compared to petrol vehicles would only fall between 17% and 30% (Ecologistas en Acción, 2020).

However, in Barcelona there is an additional problem when it comes to mobility. The city's economy is structured around the service sector: accounting for 70.4% of the province's GVA in 2010 (González *et al.*, 2015). Amongst these services, tourism is worth particular mention. The carbon footprint of more than 16.5 million international tourists in Barcelona is very high: 9.6 $MtCO_{2eq}$/year, much higher than the entire city (Figure 1). Of this amount, 78% arrive by plane, in other words, the main factor to blame for this carbon footprint (Rico *et al.*, 2019). The problem is not just the fact that internal mobility and supply is essential, but that the economy relies on a sector that is also heavily dependent on hypermobility.

4. Food and water

Following a temperature increase of 2 ºC, there would be a net decrease in the yield of harvests (Peñuelas *et al.*, 2017) and the nutritional quality of food (Högy and Fangmeier, 2013). Furthermore, access to water would be more scarce; salt-water would encroach on coastal aquifers; there would be an increase in erosion on account of dryer seasons followed by flooding; the rate of wildfires would be higher; and given the speed of climate change, it would be impossible to adapt harvests to these new conditions[7]. This would place the ability to feed the population in jeopardy.

However, the urban problem is much more serious, as cities are unable to produce the food they consume. In 2013, they consumed 1.1 million tonnes of food traded at Mercabarna, Barcelona's wholesale market. This figure continues to grow, as does the distance of place of origin of the food. In the case of fruit (which ranks second in terms of tonnes, not far behind first place), more than a third has travelled more than 2,000 km to reach Barcelona (Cotarelo, 2015).

Table 1. Food sold at Mercabarna in 2013 in tonnes

	Meat	Fish and fresh seafood	Fish and frozen seafood	Vegetables and others	Fruit	Total
Food	21,519	61,471	11,792	526,096	516,128	1,137,006

Source: Cotarelo (2015).

In any case, a significant part of the food needed could be produced in the city itself, as is already the case in Havana, Detroit or Rosario[8]. However, without the mass use of oil, this change will be difficult: whole blocks would need to be demolished, roads torn up, the soil decontaminated and water provided. Furthermore, foodstuffs like cereal, for which large areas are required, would have to be grown outside the city all the same. This change is no mean feat. It might not even be possible.

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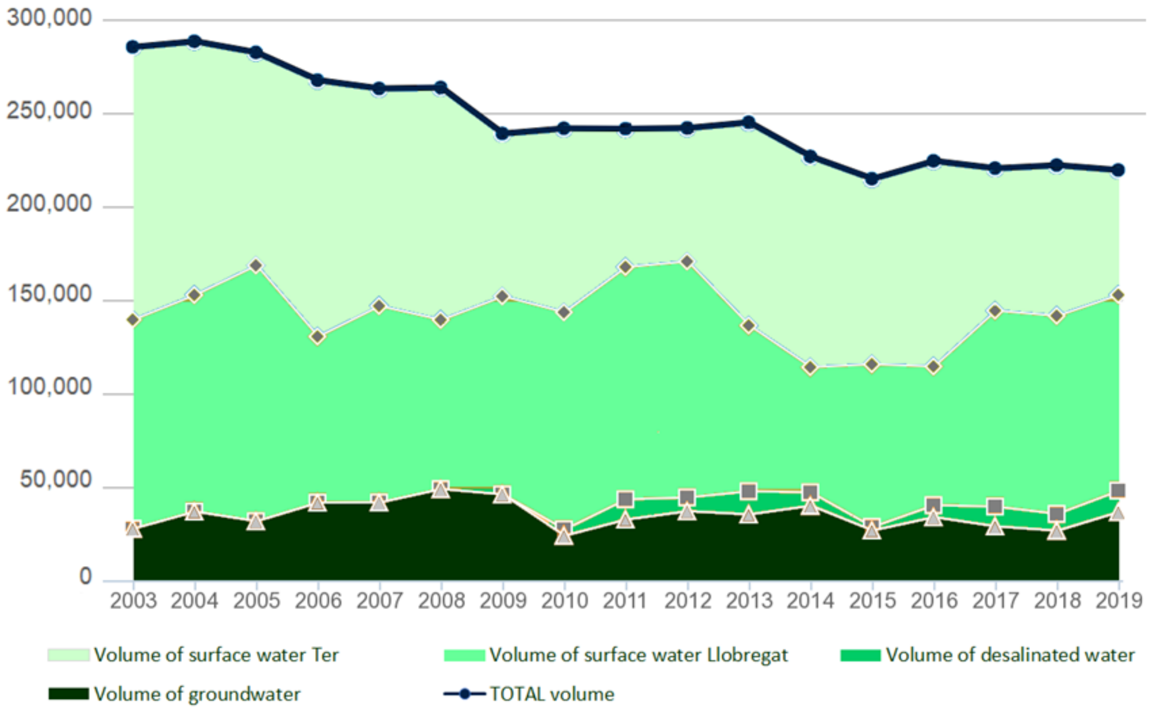
6. The global energy cost of this would be similar to the annual energy cost of oil extraction (García-Olivares et al. 2018).
7. Elliott *et al.* (2014) predict that the loss of between 400 and 2,600 cal/person as a result of global warming (8 %-43 % of current levels) may increase to between 600 and 2,900 cal/person when including the loss of irrigated land as a result of climate change.
8. In Havana, urban agriculture accounts for around 70% of all food. Detroit produces around 15% of the food consumed by the city and 50% when taking the surrounding areas into account (Fernández Casadevante and Morán, 2015).

In terms of water, in Barcelona 64 hm^3 per year was consumed by households, 26 hm^3 by industry and commerce and 5 hm^3 by the public sector in 2013 (Cotarelo, 2015). However, the contributions from natural systems that supply Barcelona fell by almost 20% between 1996 and 2005 compared to 1940 to 1995 (Ecologistas en Acción, 2016), and this trend has continued (Graph 2). Climate change is behind this process, which will inevitably continue this upward trend.

Graph 2. Water resources available in the Barcelona Metropolitan Area in thousands of cubic metres



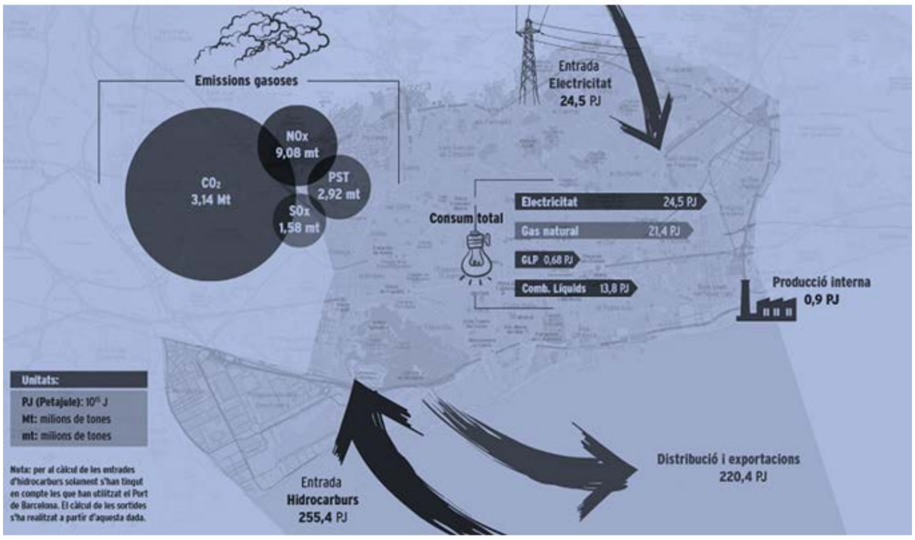
Source: BMA (2020).

Undoubtedly, consumption could be reduced by reducing losses (which are significant) and making lifestyle changes. First, with household consumption accounting for the majority of water use, rising temperatures will not leave much room for manoeuvre. Furthermore, water is likely to experience high levels of tension in terms of its use; for starters, agriculture, which will require growing amounts against a backdrop of increasing water stress. In short, water is another determining factor in the increasingly compromised metabolism of urban environments.

5. Energy

Since 2018, Barcelona Energía has managed 41 photovoltaic facilities installed in municipal buildings, the Sant Adrià del Besós incinerator and the Garraf biogas plant. In total, these plants transfer 1.3% of the city's consumption to the grid (author's calculation based on data from Barcelona City Council, 2020b). Cotarelo (2015) provides a more comprehensive view of Barcelona's energy metabolism (figure 1). The obvious conclusion here is that there is a huge reliance on energy generated elsewhere.

Figure 1. Barcelona's energy metabolism in 2013



Source: Cotarelo (2015)
Note: To calculate the hydrocarbon input, only those used at the Port of Barcelona have been taken into consideration. The calculation of outputs has been carried out using this information.

The issue here is not only the significant reliance on the outside world, but that these energy flows (including food) rely on sources that are located thousands of kilometres from the city (Figure 2).

Figure 2. Source of input energy flows in Barcelona

Source: Cotarelo (2015)

Therefore, it is no surprise that the energy resources mostly correspond to goods entering the city via the Port of Barcelona, although many of them are not dedicated to internal consumption (internal consumption accounts for 22% of energy imports) (Cotarelo, 2015).

Believing that this huge reliance on energy produced elsewhere can be covered simply by committing to renewable energy and sustainable transport is unrealistic. Less so considering the time-frames available. A sustainable energy metabolism for the city of Barcelona inevitably involves significantly reducing energy consumption, which in turn requires a decline in urban population.

Renewable energy (including biomass) will not be enough to maintain current levels of consumption and, using the technology currently available, we would barely cover half of the world's consumption in a best case scenario (Fernández Durán and González Reyes, 2018).

These limitations can be traced to three factors: the lack of concentration of renewable energy; the fact that, compared to fossil fuels, which can be stored, renewable energy takes the form of energy flows; and that the net energy provided by many of them is low. Physical issues, rather than technical issues, reduce the potential of renewable energy. And physical issues are non-negotiable.

This, combined with the fact that the industrial and hypertechnological format of renewable energies are an extension of fossil fuels, rather than autonomous sources of energy. They all require a mining input and the processing of a range of compounds that are achieved thanks to fossil fuels. They also require heavy machinery that can only be powered by fossil fuels.

Currently, renewable energy is mainly used to produce electricity; however, not everything is powered by electricity. Around 75% of energy consumption in Spain is non-electric. Specifically, electricity is not ideal when it comes to powering trucks, tractors and diggers that require autonomy of movement, as their batteries are so heavy. Another sector with a strong reliance on fossil fuels is the petrochemical industry. To make matters worse, these two industries are two of the cornerstones of the Catalan economy.

The problem of the energy cost of the transition is no less great. Replacing 2% of coal-fired power capacity per year with renewable energies (assuming an energy return rate of 10:1, which is probably greater than the actual rate provided by renewable energies, over a lifetime of 40 years) requires an energy investment four times greater than the capacity to be installed, as nature is unable to offer an advance on energy credit (a wind turbine cannot be manufactured using tomorrow's energy). In reality, this entails a reduction in available power of 8%, rather than 2%. Therefore, investing in the energy transition involves reducing the energy available in the short term more quickly than would be the case if the commitment to a new energy model were not made. Only after seven years (more than one term in office) would the energy investment surpass the decline in fossil fuels. And the greater the amount of renewable energy to be installed immediately, the greater the energy investment, the decline in total energy available and the time from which the investment would be offset (Murphy, 2013).

Another factor that must be taken into consideration is time, as the time frames required to build the new infrastructures encroach on the drop in the availability of fossil fuels (the peaks of availability that have not yet been reached would be achieved in the coming years, or decades at most) and, therefore, represent a significant hurdle to an orderly energy transition. As part of the fossil fuel monopoly, new energy production systems have been installed over 50-75 years (Podobnik, 2006; Smil, 2017). And sources were not actually replaced in any cases; rather they were added. Instead of consumption being reduced, it was increased.

As if that were not enough, various elements that are key to the development of high-technology renewable energy are not available in sufficient volumes to support the mass explosion (Capellán-Pérez et al., 2019).

6. Materials

We will perform an analysis of Barcelona's material reliance based on the data for Catalonia, which are readily available. Furthermore, this is prudent from the perspective of sustainability: Barcelona needs to enhance its reliance on nearby production and extraction, i.e., sources within Catalonia. The functioning of the Catalan economy is based around the transformation of imports at early stages of transformation into manufactured products. It imports increasingly more consumables (fuels, minerals, agricultural biomass) to supply its main industries (food, automotive, chemicals), which in turn feed its exports[9] (González *et al.*, 2015). The net physical balance is well in the red,

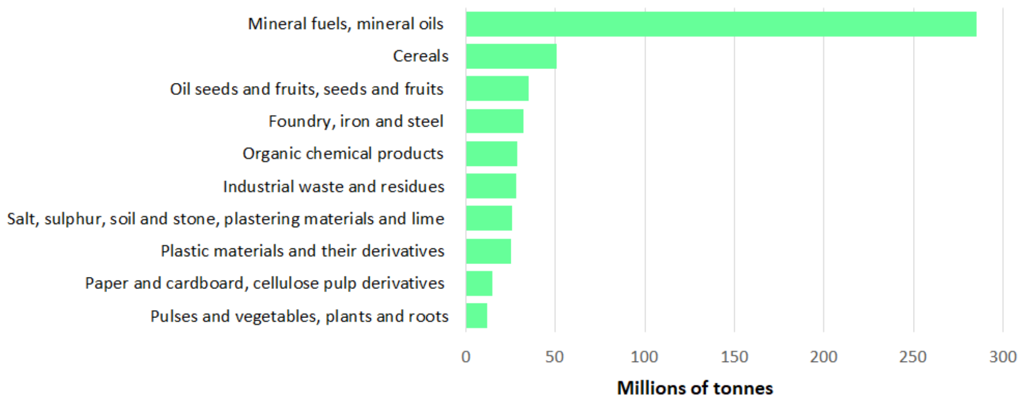
9. Domestic extraction is mainly biomass (8.1 million tonnes in 2016), although for the main part non-metallic minerals (26.8 million tonnes in 2016) (IDESCAT, 2020), of which the most important fraction corresponds to construction materials (González *et al.*, 2015).

standing at minus 47 million tonnes in 2016 (IDESCAT, 2020) (graph 3). In other words, it is a productive economy based on the mass consumption of fossil fuels, minerals and biomass, while at the same time being focussed on promoting mass consumption. The systemic crisis has put all of these under massive strain.

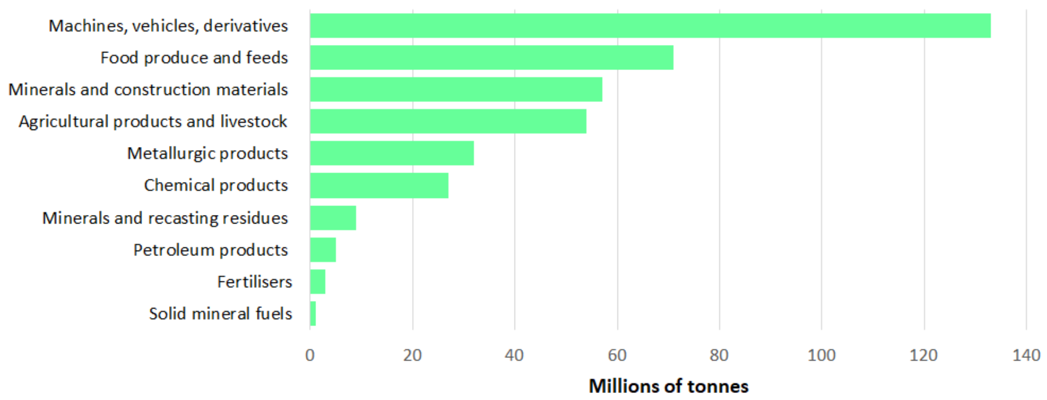
The main entry point for all these materials is the Port of Barcelona, with 35 million tonnes arriving in 2018 (not including foodstuffs, fish and local movement), of which almost 10 million tonnes were liquid petroleum (IDESCAT, 2020).

Graph 3. International imports (a) and from the rest of Spain (b) cumulative from 1996 to 2010 in millions of tonnes in Catalonia. Physical trade balance (c)

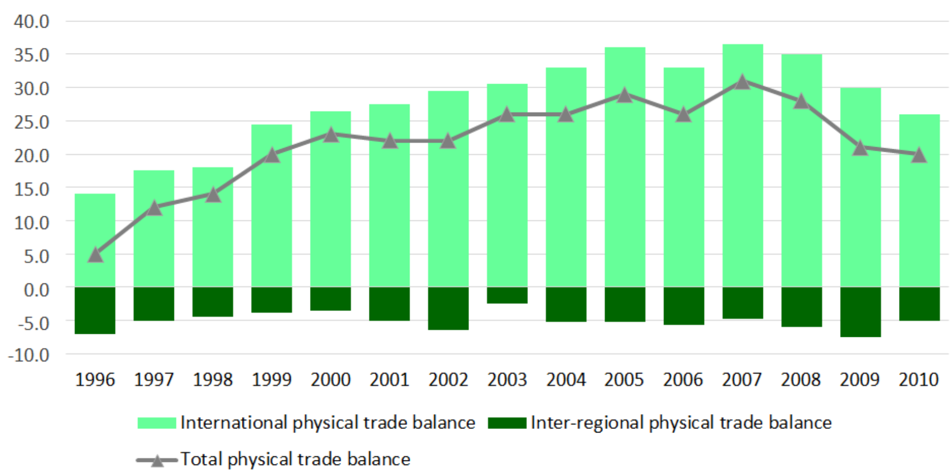
(a) International imports



(b) Imports from the rest of Spain



(c) Physical trade balance



Source: González *et al.* (2015)

Faced with this, there are calls for a move towards a dematerialised economy and smart cities. This proposal is structured around an increase in efficiency thanks to the option of transferring data online. However, claims of the computerised world being of an immaterial nature and having a harmless environmental impact are unfounded. For example, the construction of a computer requires the extraction and processing of 1,000 times its weight in material, with the transportation of products that this entails and the ecological impact of its production. Furthermore, the materials used in their construction are scarce. The issue lies not just in the resources employed as part of their production, but the contaminating waste they generate. Furthermore, the functioning of cyberspace and image society require a considerable amount of energy: when adding together the entire life cycle of devices, ICTs account for more than 4% of all energy (not just electricity) consumed on the planet (Turiel, 2018). Finally, there is no data to support the existence of such a dematerialisation (Parrique *et al.*, 2019).

7. Residues

The urban metabolism ultimately leads to waste. This is because the metabolism of cities is distinctly linear, rather than circular.

In terms of waste gas, the CO_2 emissions generated by the combustion of liquid fuels in Barcelona came to 3.14 million tonnes in 2013 (Figure 1). This confirms that urban centres are hubs of greenhouse gas emissions and that this situation is structural, as we have suggested.

In addition to this are the sulphur and nitrogen oxides and suspended particles (Figure 1) responsible for Barcelona's terrible air quality: in 2018, the Barcelona area once again exceeded the annual threshold for nitrogen dioxide and suspended particles measured at different stations (Ecologistas en Acción, 2019).

In 2018, Barcelona treated 265,000,000 million cubic metres of wastewater (BMA, 2020), accounting for just 2% of all the city’s electricity consumption. In reality, energy consumption by the water network is much larger, as the pumping required as part of the supply, the treatment of drinking water and maintenance of infrastructures must all be taken into account. In terms of solid waste, in 2018, 1.6 million tonnes (459.5 kg per person) were generated, of which just 35.7 % was recycled or composted (BMA, 2020), confirming the linear nature of the urban metabolism.

Faced with these issues, there has been an increased commitment to the circular economy. However, the real circular economy, in which the reuse rate of elements can reach up to 99 %, is only achieved by nature. And let us not kid ourselves, these are the rates needed in a world of finite resources. To achieve this, the economy must be completely integrated into ecosystems. Only then will this feat be feasible. This requires economic systems based on solar power, biological products, refraining from using xenobiotics, travel over short distances and slow, small metabolisms (González Reyes, 2017). These factors are an impossible fit when it comes to major cities.

8. From the city to the countryside

The structural unsustainability of cities does not necessarily mean that the measures that mitigate their impact and increase their resilience to climate change would be unwelcome; particularly as the effects of global warming hit the most disadvantaged populations the hardest and they must receive protection. Simply, we should not get our expectations up about them being feasible in big cities in the medium term. The urban policies required involve reducing energy consumption and the transition of big cities towards a renewable model; however, these policies will most likely need to look beyond cities.

Renewable energy must really be renewable; in other words, energy produced with energy and materials that are actually renewable. In other words, those that for the large part use biomass and minerals that are in abundance. As a result of this ecosystemic crisis, a solid approach to managing and choosing biomass destinations is required. To achieve this, sights must be set on rural areas.

We also need renewable energy for much more than just producing electricity. For example, we need to recover machines that use the mechanical energy produced by water or wind to work. This entails decentralising production spaces and relocating them in areas in which renewable energies can bear fruit.

However, renewable energies are not limited to just wind, sun and water. Renewable energies include those provided by our muscles and the energy provided by other animals. Think of humans as self-repairing machines (when the damage is not serious), that are powered by 100% renewable and highly versatile sources. This revitalisation of human and animal work involves, among other factors, populating rural areas to undertake agricultural work as the powerful machinery that currently performs this work starts to become more scarce.

There are no substitutes for oil that can sustain transporting large amounts of information, goods and people over large distances in short spaces of time. This will force us to move towards local economies. Economies will not only be more local; rather, they will also be essentially agricultural, as an industrial society can only be supported by fossil fuels.

Furthermore, decarbonising the economy within the time frames required to prevent climate change from running amok requires the removal of significant amounts of CO_2 from the atmosphere in addition to refraining from using fossil fuels. This can be achieved by applying policies for the mass renaturalisation of large regions and a staunch commitment to organic farming.

Renewable energy to power work, humans and animals as energy carriers, renewable sources of material, local and agrarian economies, rewilding, etc. requires a central objective for the eco-social transition: coordinating a living rural and agro-ecological world.

This objective is neither small nor simple. It requires a change in the way we view the rural world: revaluing it to the detriment of the urban world. To this end, significant investments are needed (which would likely be removed from urban spaces). For example, in public services (which are more expensive than in cities, as each infrastructure attends to a smaller number of people). In addition to legislation that promotes the rural exodus. At a municipal level, for example, reclassifying urban land in cities as land that cannot be used for building purposes. At a state level, revoking free trade treaties entered into and implementing regulations that prioritise fair and sustainable local production. And, as goes without saying, undertaking an agricultural reform process that fights against the division of land into large estates in favour of the community management of land.

In conclusion, we need to talk much more about the rural world than the urban world, as revitalising the former and dismantling the latter is imperative.

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