Cities as Resilience Systems: up-date of Environmental Urban Curve.

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1. Introduction

The modern metropolis can be thought as structures whose order is maintained through an energy dissipation which is far from its point of equilibrium. This hypothesis was born more than thirty years ago from the debate generated by the Nobel Ilya Prigogine together with Peter M. Allen e Robert Herman in '*The Evolution of Complexity and the Laws of Nature. A Contribution to the 3° Generation Report to the Club of Rome: Goals for a Global Society*' (1979). Dissipative structures (Prigogine I., 1979) are defined as particular organisations of matter and Energy in open systems and are at the basis- from a physical and environmental perspective- of ordered systems and autopoietic systems (Maturana e Varela, 1985). The environmental consequences of this thesis remain to be investigated but the idea of the city as a social form of an energetic system is intimately connected to the relationship city-natural resources and entropy-environment (Georgescu-Roegen, 1971).

The model to whom this phenomenon can be easily compared is that of a thin layer of liquid in a tank, heated uniformly from below: "When the heating is moderate, the liquid is in the second regime of linear non-equilibrium and the heat passes through the liquid by conduction. As the heating is intensified, however, at a well-defined temperature gradient, suddenly, the cells convention spontaneously occurs "(Prigogine, Allen, Herman, 1979, p.19). These dissipative structures, called "Bénard cells" (named after the physicist who discovered them, Henry Benard), are hexagonal in shape and recall, although only for the planar pattern, the equilibrium of the markets' distribution as defined by Walter Christaller (1933). They give rise to an morphological order which is kept alive by a high energy dissipation around certain defined threshold values.

This is possible due to their nature of 'open systems' that can exchange both matter and energy with the environment: "The city as a dissipative structure receives inputs and high-quality resources from the outside, for example, from the sun, the surrounding countryside or the port-goods. These resources are transformed into components of the structure of the city or used to support the structure responsible for the organization of the city itself. Eventually, the degraded resources are discharged into the external environment [...] as waste of matter and energy (entropy) "(Tiezzi, 1998, p. 85).

In isolated systems, the exchange is denied, and neither matter nor energy can flow from the external environment. In closed systems, instead, there is exchange of energy but not matter with the environment. The flow of energy and matter is what we denote by the term 'resources' not only in economy but also in ecology and physics. The amount of energy and matter extracted and processed determines also the various productive and connective organizations, the networks that allow the exchange, and therefore generate the specific social and economic structures.

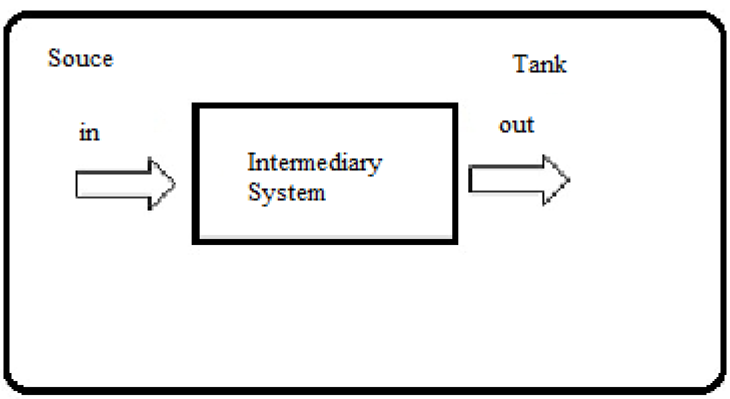
Typically, only a small fraction of the flows of matter and energy which passes through an open system stops with it, the rest flows towards the exterior environment, resulting in a balance between inputs and outputs. Living systems, social organisms, geo-economic systems, namely the set of 'autopoietic' systems, are systems that use the flows of matter and energy to maintain their internal order. The maintenance of the structure involves the qualitative degradation of the flows of matter and energy, that, while maintaining the input and output quantities (according to the first law of thermodynamics), change their type, their informative content, their structure and quality . Useful products and high quality energy are transformed into waste which have to be regenerated or recycled.

There is a paradox interestingly examined by Georgescu-Roegen in his seminal work (1971): the second law of thermodynamics, which states a tendency of systems towards the "entropic death", is contradicted by the practice of biological, social, economic and territorial systems that, rather, perpetually create a new order: new lives are constantly generated in the world of both plants and animals, new organizations, new cities, new organisms are created and spread.

The resolution of this apparent contradiction between the socio-biological and the physical world lies in " the fact that the second law of thermodynamics applies to systems near equilibrium" (HJ Morowitz, 1979) namely isolated (adiabatic) or isothermal systems. Human activity and the organization of territory do not belong to these classes, they are indeed all systems far from thermodynamic equilibrium. It is possible to define them as "systems of systems".

The diagram of Morowitz, ie a system inserted in a meta-system (the environment), describes the following situation. The environmental meta-system contains the energy sources and the reservoirs of discharge of the other part of the intermediate system, such as, in this case, a city.

Figure 1 – Morowitz's System



The variation of entropy S, in the time dt, which is denoted by dS, is given by the formula:

$$dS=dSe+dSi > 0 \quad (1)$$

where dSe is the entropy of the external system and dSi represents the entropy produced by the intermediate system (eg a city). The total entropy of the system will, for the second law of thermodynamics, remain always positive: dS> 0, but this does not imply that the intermediate system

must be entropic. The only restriction placed by the second law of thermodynamics will be for (1) that: deS > - diS.

So it is possible to have negentropy and order in the intermediate system given that dSi <0.

In other words, "living organisms counteract the tendency of the universe to pass from order to disorder; they are indeed able to create order in their organism while keeping it alive with their biological functioning, causing an increase in the disorder of their surrounding environment. The overall balance therefore respects the rule of entropy "(Bresso, 1993, p. 54).

Entropy in a dissipative structure (which is to say a structure that dissipates the energy of the external system, the metasystem) may decrease (negentropy) if the intermediate system is crossed by large flows of energy. The city belongs to this typology of structure : it maintains the internal social order (namely its regulation) due to the input of massive flows of energy (used for heating, transportation, creation and consumption of products, services, etc.).

If one considers the city as such, it is an energy-consuming organism characterized by a high level of consumption, a dissipative structure with very high internal organization. As Odum claims "The money circulates in the economy among the people but does not pay the processes and components which can be found in the natural world (...) Within the human economy, flows of both energy and emergy converge on centers, this explains the settlements and cities. "(Odum, 2005, p. 105).

According to the analysis conducted by IRES dealing with the emergy accounting (Ferlaino and Tiezzi, 2001) or the ecological footprint (Bagliani M., F. Ferlaino, Martini F., 2005, Bagliani et al, 2012), of the city of Turin and the region Piedmont corroborate this hypothesis : the ecological footprint of Piedmont is 22,237,640 gha (global hectars), equal to 5.28 gha per capita. Its biocapacity (namely its useful ecological land in global hectars) is only 4,607,018 gha and therefore its ecological deficit amounted to 17,630,622 gha, equal to 4.18 gha per capita. The province of Turin represents about 47% of the total footprint of Piedmont (Bagliani M., F. Ferlaino, S. Procopio, 2002) and it is estimated at 4 million gha, slightly less than the entire regional biocapacity. This means that a city as big as Turin would need the entire biocapacity of the Piedmont region to be sustainable. This figure can be considered as very low if compared to Tokyo that requires twice the area of Japan or London, which requires twice the area of the biologically productive land of Great Britain, something as the whole of Spain (some of these figures are available at http://www.gdrc.org/uem/footprints/index.html).

This significant energy dissipation (and its physical and operational transformation) is the cost to be paid for the welfare and the structural complexity (dealing with both the organization and the decision-making process) of a large town or a city. Although there are considerable potential savings which can be achieved through a higher productivity of matter and energy, as soundly suggested by the Wuppertal Institut (von Weizsacker et al, 1998; Kuhndt, 2005), the morphology of the urban territory always needs a strong energy dissipation through which the city can maintain the current levels of ‘functional complexity’. Where, we know it, ‘functional complexity’ is a concept which is difficult to define and easy to understand. In extreme synthesis it can be seen as the possibility for each individual to play a social role and tot end towards an end, to be, therefore, integrated and to be an active agent within the social system (Parsons, 1951). The system becomes more complex when it absorbs into this process the augmentation of the population (namely its components); on the contrary, it would tend to become simpler when it is not possible to integrate an increasing part of the population.

3. The Environmental Kuznets Curve and the I-PAT Equation

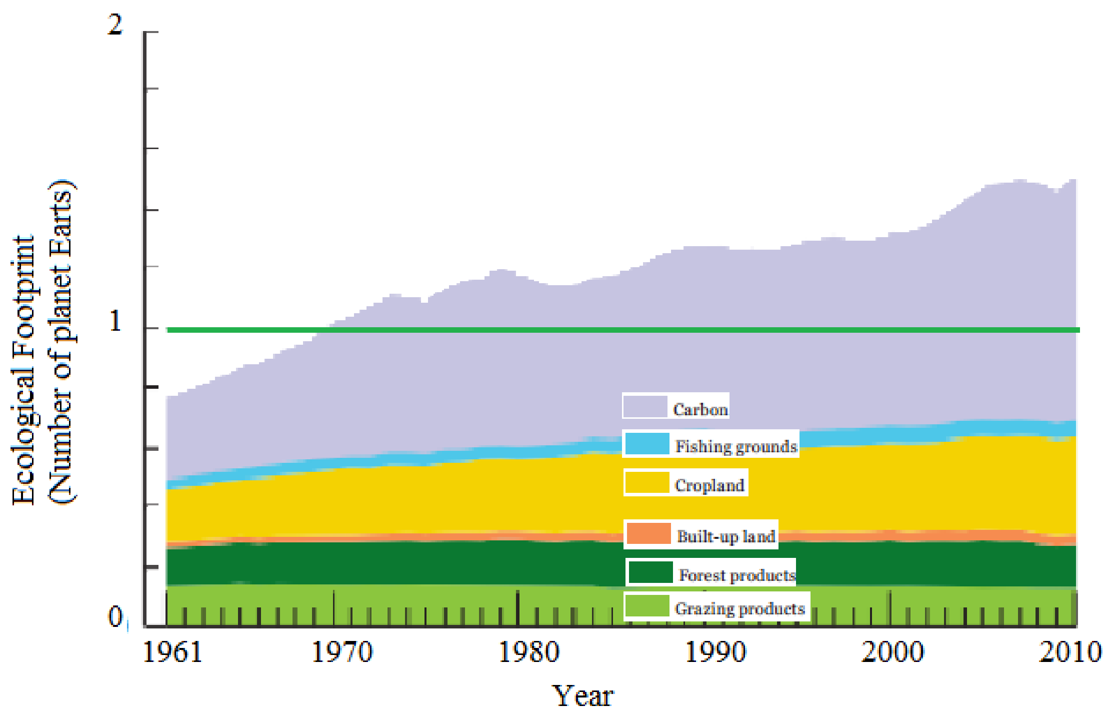
A city is a negentropic system. It is, therefore, a territory that requires high energy flows in order to maintain its internal order. These flows can be sustainable or not. They are sustainable if they meet certain criteria defined by economist Herman Daly (Daly, 1981), namely:

- the *Principle of sustainable efficiency*: the resources must be consumed at a rate that allows the environmental system to restore them.
- and the *Principle of absorptive capacity*: the production of goods must not generate wastes, discards and pollutants that cannot be absorbed by the system in a reasonably short time; there must be no cumulative effects.

The entire metabolic system, in extreme synthesis, is simply the transformation of (physical) natural capital (especially the materials collected in the primary and mining sector) through the use (a particular organization) of energy (derived both from the human work and from the machinery). The transformation of matter without form into matter that has a form which is connected to its function and employment is clearly a negentropic action that needs, as we have seen, a high energy flow. The cycle of transformation of natural capital must respect the principles of Daly to be sustainable over time. The *cycle* is in equilibrium *if the speed of the phase of consumption [of the resources] is equal to the speed of the phase of regeneration*. If the law of equality between *consumption* and *regeneration* is not observed there is an accumulation of waste that will impact on the glocal territory.

This balance is not respected today, as it is show in figure 2 (WWF, 2010). From the mid-eighties, the Earth does not regenerate the consumption of natural capital (in particular the excessive production of CO2) and this unsustainability continues to increase. The day in which the biocapacity of the Earth reaches the amount of natural capital consumed during the year is called *Earth Overshoot Day* and it has been defined as “the day of the year in which human demand on the biosphere exceeds what it can regenerate”. In 2012, it has been conventionally placed at the 22th of August. From August 22 to December 31 the wastes produced are not absorbed, therefore they impact on the global territory and change the balance of the ecosystem. What has to be done in order to restore sustainability?

Fig. 2 Ecological Footprint broken down by its various components (1961-2005).



Source: WWF, 2014

A positive and liberal response to the question of sustainability is given by the proponents of the Environmental Kuznets Curve '(EKC). According to these theorists, the economic growth would lead to an increase of the environmental impact until a certain threshold (the turning point)and to a decrease of this variable in a second stage. This curve is inverted U-shaped and scholars are currently debating to understand if it possible to identify Kunsets' Curves in relation to the environmental consumptions and for which reasons. Others scholars have suggested different strategies, the "zero growth" economy (Meadows et al., 1972) or, more recently, the " happy degrowth" (Latouche, 2007). This question is therefore posed in terms of 'growth', 'zero growth' or 'degrowth'.

The I-PAT equation of Ehrlich and Holdren (1971), however,makes scenarios of 'zero growth' and 'degrowth' (at least a "happy degrowth") quite unlikely, especially at the global scale, as one of the factors, the population, will continue to increase in the medium and long-term. The equation expresses the total impact as a multiplicative effect of the population (stock), of the measurement of consumptions (behaviors) and of the present state of technology (environmental efficiency of production).

Impact (I)= Population (P) x Affluence (A) Technology (T) (1)

Where:

A = consumption per capita (C / P)

T = the impact per unit of consumption (I / C)

In quantitative terms, the formula becomes

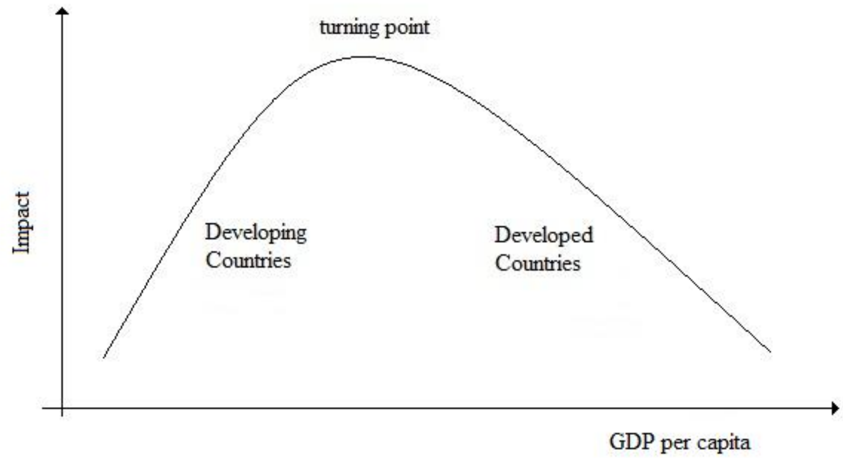
$$I = P \cdot \frac{C}{P} \cdot \frac{I}{C} \qquad (2)$$

Which is equivalent to

$$I = P \cdot \frac{GDP}{P} \cdot \frac{I}{GDP} \qquad (3)$$

Both the first factor, the population (P) and the second factor, the amount of consumption (GDP per capita) are growing, while there is a vast literature that questions the hypothesis of Kuznets and the trade-off of environmental impact (I) and wealth (GDP), in mature economies (Cantore, 2005; OECD, 2002). This debate focuses on the third factor of the I-PAT Equation, the possible decrease in the impact of technology within mature local systems and, therefore, the relative increase in productivity per unit of energy and matter consumed. The increase in energy productivity together with the growing dematerialization of goods would lead to the "natural" 'detachment' (delinking or decoupling) of growth of the GDP from the growth of natural capital consumption.

Fig 3 - The Environmental Kuznets Curve.



The issue of 'delinking' is rather debated (Mazzanti, Zoboli, 2005, Singer 2010) and it is centered around the demonstration of the theoretical hypothesis which states that the impact of technology grows at low levels of GDP, then reaches a peak, inverts the curve and begins to decreases in conjunction with higher levels of wealth. In the neoliberal economy "the rich are never dirty". Is it true?

4. I-PAT Equation and cities

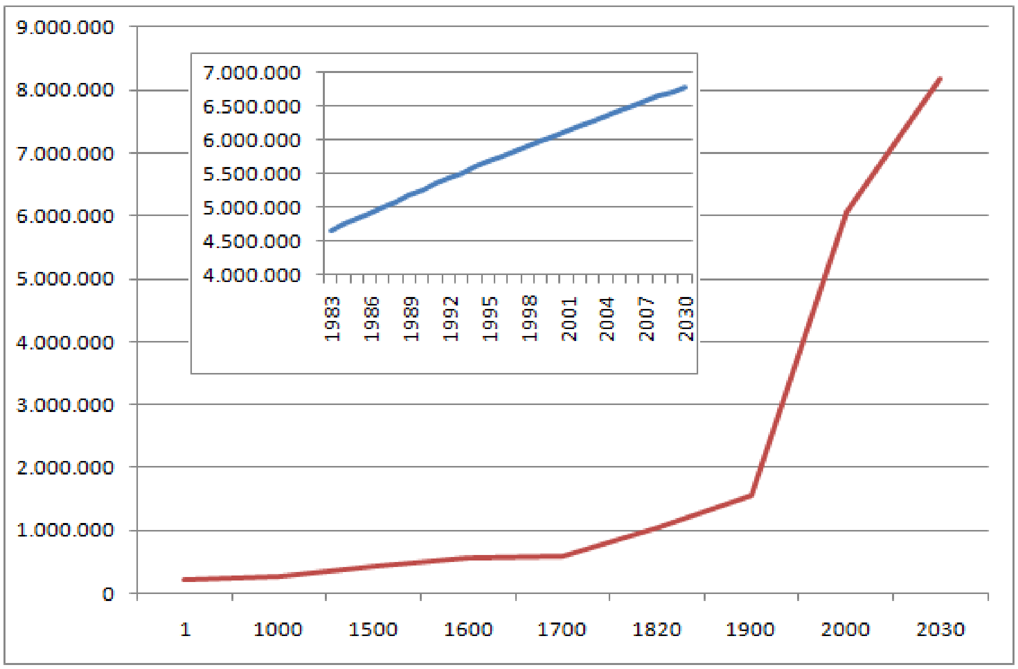
What is underestimated in the current theories is a territorial vision of the effects which, as will be demonstrated, have implications that are quite different from what is commonly exposed in the literature. A different hypothesis of the EK-curves can be formulated. It refers to the urban environment, seen as an adaptive morphology that responds to both economic purposes (the increase in consumption per capita) and environmental purposes (reducing per capita energy consumption) . The classical formulation of EK-Curve is, in fact, the result of a false cause and a false correlation.

In order to demonstrate this, it is necessary to take into consideration the I-PAT equation (3) and briefly analyze each of the members, Population (P), Affluence the (GDP / P) and Technology (I / GDP), considering that the equation should be understood form a qualitative perspective rather than from quantitative one because the different terms (Population, Affluence and Technolgy) are not independent but interact trough some dynamics based on the central role of cities in the process of consumption and production.

It is very well-known that, the global population (the first term) has grown exponentially in the world until the beginning of the first years of the new century and now, presumably following the trend of a logistic equation (figure 4), tends to move towards a new carrying capacity, an asymptote and a new balance. It 's still difficult to quantitatively indicate this new equilibrium, but the UN hypotheses suggest a scenario of a minimum of 7.9 billion inhabitants in 2050, and a maximum of 10.46 billion (UN, 2009) while the inflection of the logistic equation seems to have been reached only a few years ago. However "the end of the twentieth century is marked by a demographic slowdown that suggests the possibility of stabilizing the world population" (Véron, 2009, p.513). In fact, the stabilization of the population is a strong assumption, and the process, as shown in the theory of systems, could tend

towards an asymptote as well as fluctuate in time and / or be subject to a sudden "catastrophic fall" (Thom, 1985). What happened on Easter Island is, in this sense, a warning to remember: the Rapa-Nui civilisation was destroyed; its inhabitants that Capitan Cook already described in 1774 as “minute, emaciated, shy and un happy”, due to the destruction of environmental resources (woods and agriculture), were 7000 in the Sixteenth Century and became 1500 at the beginning of the Nineteenth Century; this demographic change required a deep change of the social, cultural and organisational structure which took place in the form of continuous wars and tensions that degenerated into the practice of cannibalism and infanticide (Diamond, 2005). In this case – the one of a close system - Malthus was right.

Fig.4. The growth of the world population.



Source: A. Maddison, (2014) cheked in J.de Vries (1984, tavv. 3.2, 3.6, 3.7), OECD (1995); CIA (2014).

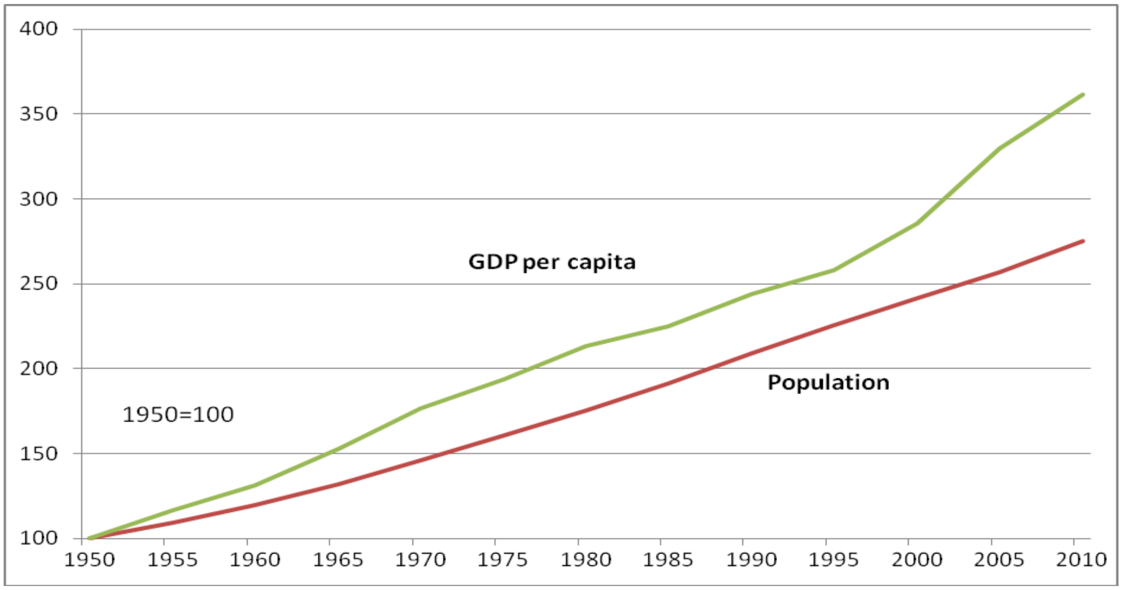
The growth of the world population is changing from an exponential to a logistics function. Assuming that the most optimistic scenario (that the stabilization of the population) will be realized (OECD, 2001) it is still necessary to examine the compatibility of this "new balance" with the environmental resources since, according to the results of the Living Planet Report (WWF, 2010), the consumption of natural capital (ecological footprint) has doubled from 1961 to 2005 and is about 30% higher than the one that the planet can regenerate in a year.

The factor Population (P) is certainly the major source of environmental impact and is also the most difficult factor to change in the short term. Furthermore, many economists regard the decrease of this factor as a catastrophe because it could lead to destabilizing scenarios in the economic and social structure.

The economic importance of this factor emerges if we compare its growth with that of the second factor, the GDP / P: considering the data starting from 1950, when both the population and GDP per capita worldwide had a value of 100, it is interesting to note that while the former has a quasi-linear

trend in recent years, the second, the Affluence (consumption), has a trend which is more than proportional (figure 5).

Figure 5. The relationship between population growth and gross domestic product (average) in the world (1950 = 100).

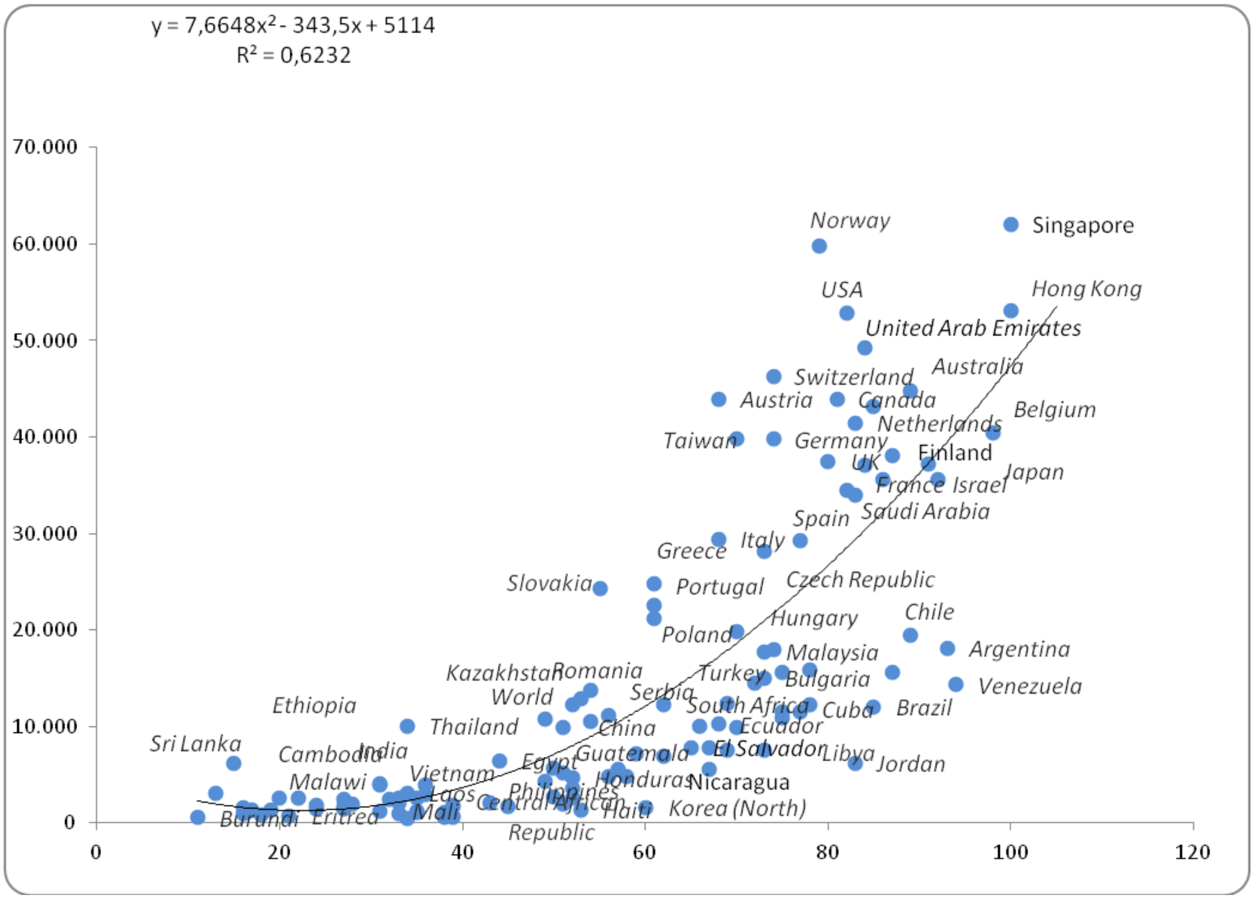


Source: A. Maddison (2014), checked in Bolt, J. and J. L. van Zanden (2013); CIA (2014)

The role of the cities in the population growth has been extensively debated. The literature has highlighted the correlation between industrial growth, population growth and urban development. This relationship however has become rather complex in the post-industrial and knowledge society. Considering relatively large territories and using a synchronic cross-country analysis some paths of development can be traced: they are different but they can be ascribed to some stable macro-dynamics of growth. In particular we considered in our study only the states with more than 5 million inhabitants and without omissions in their database (namely with complete demographic and economic data) . In this update (the first analysis dates back to 2009), overall 120 countries out of 227 on which data are available have been considered. The average value of the population is almost 60 million inhabitants against the 1.32 million average for the rest of the countries not considered. Values of CO_2 emission has be gathered from the Data World Development Indicators of World Bank; GDP, Energy consumption, fertility rates, population and percentages of urbanization has be gathered from Th. Brinkhoff (2014) and checked out on the World Factbook (2014) of the CIA and the World Economic Outlook Database of the International Monetary Fund,, while the historical series on population and GDP have been taken from Maddison Project and Historical Statistics of the World Economy: 1-2008 AD (A.Maddison, 2010). The results are relevant.

1. The undoubted correlation between urbanization and wealth has to be noticed (R^2=0.6). The latter (Figure 6) increases more than proportionally with the consolidation of the urban model that seems to lead to a kind of economic take-off confirming many of the analyses made.

Figure 6. Correlation between GDP per capita and percentage of urban population

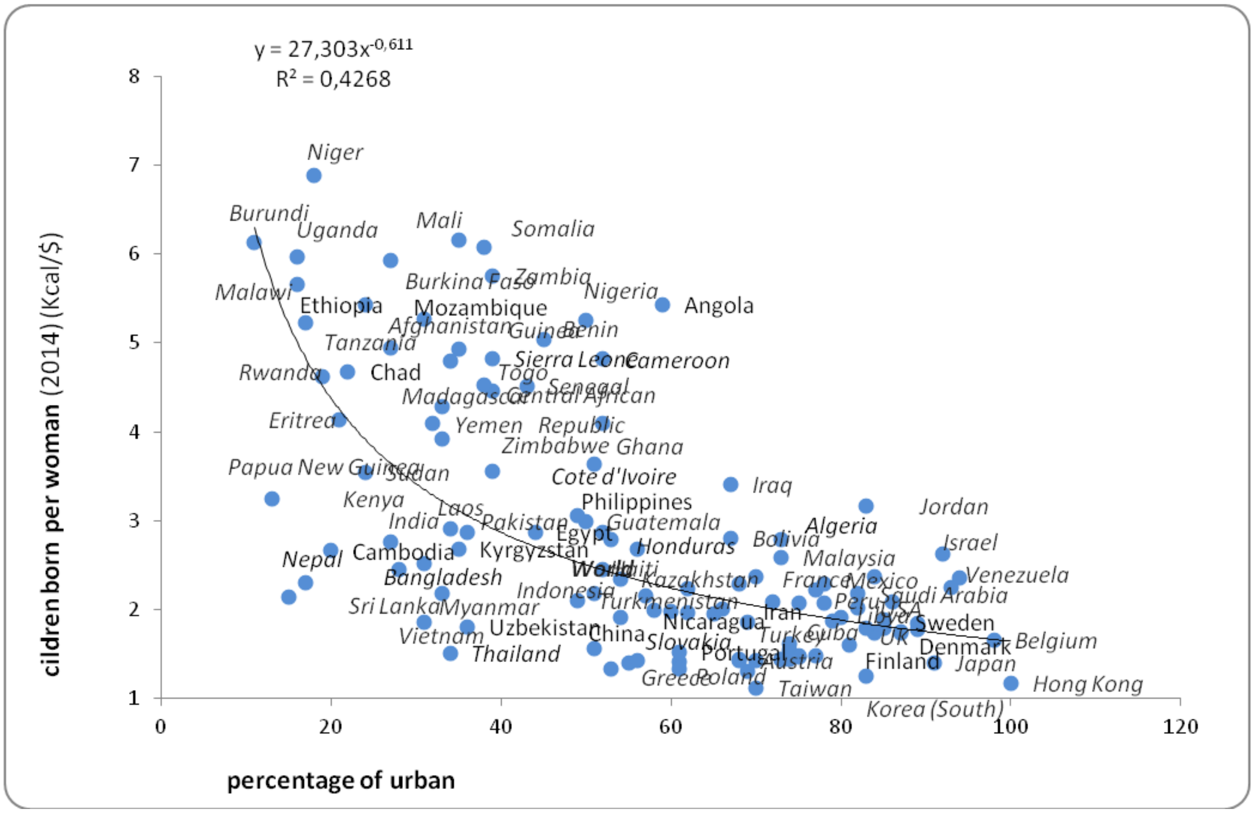


Source: Th. Brinkhoff: City Population (2014); CIA (2014)

It is possible to note that when the urbanization increases, wealth grows more than proportionally: the city seems to be an organization that tends to improve economic welfare by shifting and concentrating resources. The agglomeration and densification of the territory is a form of economic optimization because it tends to maximize the welfare of both producers and consumers (Launhardt, 1885, Rosen and Resnick, 1980).

2. The modern city is a demographic "black hole". This is the first resilience effect. Its growth can be entirely traced back to the strong attraction that it exerts on the surrounding areas and to the rural-urban migration that converge into the city as a source of prosperity. The population explosion of the last two centuries depends indeed on the complex relationship between the existence of urban industrial and post-industrial centers and the generative capacity of rural systems that they attract (a form of resistance developed by the recessive mode of production). Systems that have passed from regional and local dimension to more extended territorial spheres, namely national and now international dimensions.
If fertility rates are correlated with the rate of urbanization this relationship is evident and shows the "black hole" effect of birthrate (figure 7), the city attracts people from non-urban areas offering a certain degree of welfare (in terms of wealth and a longer life expectancy) but, in return, it limits their capacity to reproduce theirselves.

Figure 7. Relationship between the fertility rate (2014) and the percentage of urban population (2011)



Source: Th. Brinkhoff: City Population, 2014

It 's interesting to note that the more urbanization increases, the more the reproductive behaviors become homogeneous. The evolutionary paths of differentiation decreases with urbanization in the metropolis and, in the territories-cities (those with rates of urbanization of 90-100%) such as in megacities, fertility rates are very low.

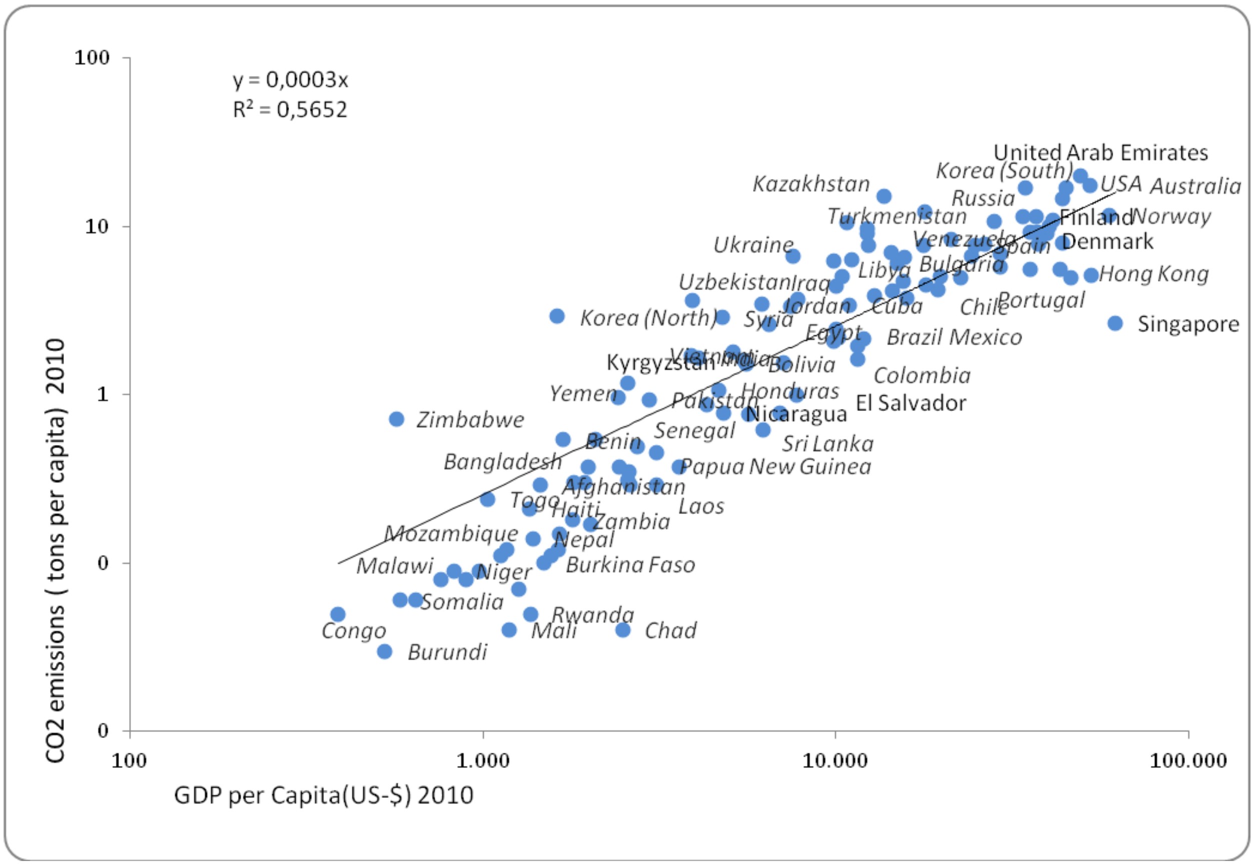
In the post-industrial metropolis, these behaviors seem to generate a demographic dynamic that tends, most likely, to a new Malthusian equilibrium. This is possible due to a process aimed at, on one hand, containing the increasing global birth rates and, on the other, to define a new threshold of quality of life. All this process takes place primarily through the imposition / choice of new reproductive behaviors, generated by a set of concomitant causes all related to the urban lifestyle: strong competition for access to resources, steady growth in productivity, but also a growing life expectancy, more needs and possibilities to change activities and roles, greater opportunities for consumption, etc.

3. The third factor, Technology, is now taken into consideration. To evaluate its impact a significant "proxy" is used, namely the energy consumption defined by the sum of oil, gas and electrical consumption standardized. Consumptions have been standardised in Kilocalories (1 $Kcal_{th}$ = 4,186 J). The assumption underpinning this indicator is that the impact generated by a thermic calorie is the same for the different sources of Energy (gas,oil, electricity). This is corroborated by the fact that 1 mc of gas (which has less impact than oil) is equivalent to 9500 kcal , while a liter of oil is equivalent to 11.000 kcal. Moreover, for what concerns the electric energy and without considering nuclear energy, only 17%

of the global electricity is produced in the world thanks to this source, while 39% derives from carbon and around 20% from hydroelectric and renewable energies.

It 's interesting to note that energy consumption is strongly (linearly) correlated with the GDP (r-squared = 0.84) and this would seem to contradict and undermine the hypothesis of the EKC at the global scale: rich countries are dirtier than poor.

Figure 8. GDP per capita and emissions of C02 per capita.



Source: Th. Brinkhoff: City Population (2014); Data World Bank (2014).

It’s also important to observe that the distribution of the different countries is characterized by a strong concentration towards the bottom (where the great majority of the poor countries can be found) and upward (developed countries) while the intermediate values are more rarefied. It follows that the process of growth tends to be dichotomous as the numerous analyzes of unbalanced development on an international scale seem to have proved.

If you instead correlate energy consumption per unit of GDP with urbanization, the intercept polynomial shows a complex relationship, tending to assume an inverted U-shape (a parabola, figure 9). The interpretation of this relation seems to suggest that the city plays a dual role: the growth of urbanization would cause an increase of the impact generated but beyond a certain threshold (about 60% of urban population) it would tend to decrease, reaching much lower intensity.

The energy consumption should therefore be related to two different kinds of process: the city would act in a first stage as an accelerator of the impact, therefore generating "growth" and, in a second

stage, that of the mature local systems, when urbanization has passed a certain threshold (over 60% - 70% of urban population) would create "development", implementing the well-being of the population and, at the same time, reducing the impacts (in relative terms, per person). A particular form of ' territorial delinking ' (Ferlaino and Lami, 2009) take place resulting in a decoupling of the urban growth from the environmental impact generated.

This process is not a canonical EKC: indeed it is not defined as a reduction of the environmental burden correlated with an increase in GDP (which grows proportionately as shown by the cross-country analysis) but correlated with a particular form of social organization, namely the urban organization. The cause of this trend does not depend on the technology used (as we have seen energy consumptions increase with wealth) but on the introduction of economies of scale that occur when the social concentration becomes greater and exceeds certain thresholds. It 's interesting to examine some aspects of these relationship:

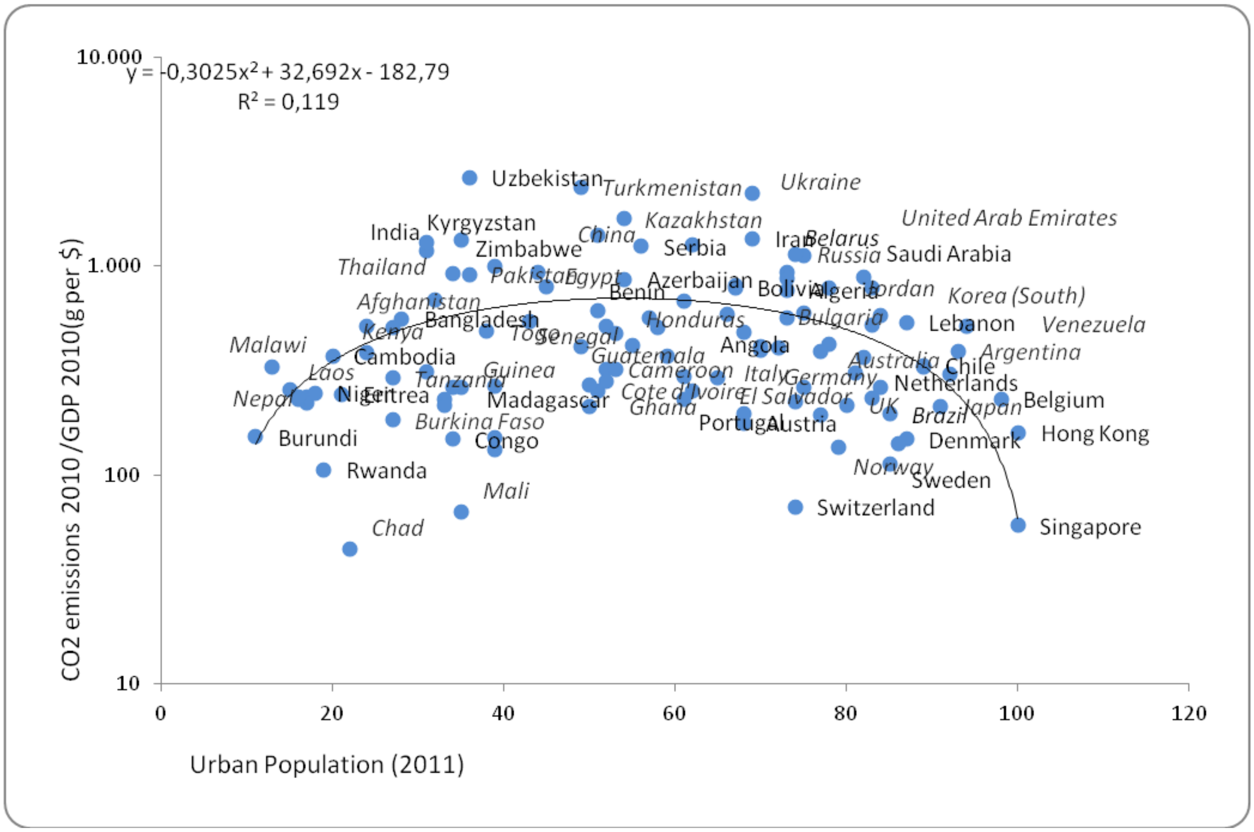
a. the intercept polynomial of second degree is in the shape of an inverted U;

b. In addition to developed countries (USA, Germany, France, UK, etc..) and to the most efficient ones (Netherlands, Sweden, etc..) other nations can be found in the upper section of the graph, namely:

some countries with lower income, but with strong rates of urban population indices in developing countries (Venezuela, Argentina, Cuba, Brazil, Jordan) ; Eastern European countries (Czech Republic, Romania, Bulgaria) and, finally, old city states like Hong Kong;

This fact can be interpreted as a particular state of 'territorial delinking 'generated by the urban organization. And this is an important factor of the resilience of the cities.

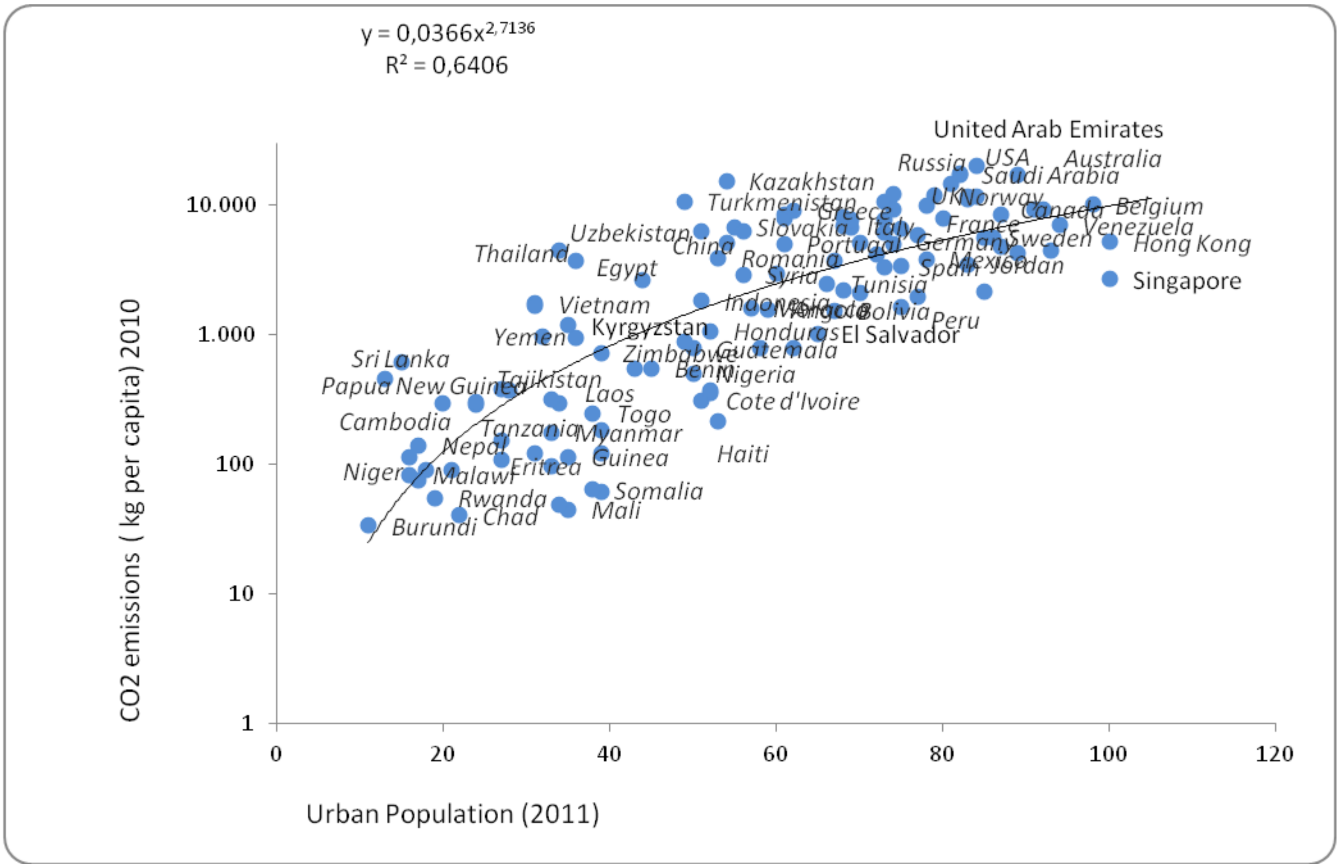
Figure 9. Relationship between the impact generated by a unit of GDP produced, and the% of urban population (2011)



Source: Data World Bank 2014; Th. Brinkhoff: City Population, 2014

The final result, the sum of the three factors I-PAT equation, implies (as measured by the indicator of the CO2 emitted) a growth of the environmental impact that tends to decrease with increasing of the urbanization. The dynamics is not easy but a little complex.

Figure 10 - Relationship between the impact generated per capita (2010), and the % of urban population (2011)



Source: Data World Bank 2014; Th. Brinkhoff: City Population, 2014

At the local scale the terms of the debate appear to be coherent with this result and highlight the role the metropolitan and urban organization plays in mature systems.

Piedmont (the region where I work) can be considered as a representative example. Emergy per person, or the energy embodied and imported from the city of Turin, in Italy, in one year (measured in joules) was, according to our data (Ferlaino, Tiezzi, 2001), half of regional one and lower than National. Also the extent of the Ecological Footprint provides the same results: Piemonte 5.28 gha/pers. while in the metropolitan province of Turin, the global hectar per person are 5.18 per year.

Is it possible to generalize these results? It would seem so. Liverpool in 2001 had a EF (Ecological Footprint) of 4.15 gha /cap., compared to an average of 4.9 gha/cap. in Great Britain (Barrett and Scott, 2001), Berlin had, in 2000, an ecological footprint of 4.06 gha / cap against 4.7 gha /cap. in Germany (Pacholsky, 2000) and in Scotland, where a very accurate analysis was carried out, five out of six cities that were considered have footprints which are lower than the national average: Edinburgh 5.12 gha/cap., Dundee 5.04, Inverness 5.00, Glasgow 4.91, Angus 4.78, against an EF (ecological footprint) of 5,35 gha/cap. for Scotland; only Aberdeen (5.37) has an ecological footprint which is higher than the National average (Chambers, Griffiths, Lewis, Jenkin, 2004).

So there is a differential between poorly and highly urbanized nations, which places the latter within more efficient processes of matter and energy production, probably dictated by the more effective local organization and by the more efficient use of the economies of scale.

5. Concluding remarks

Is it possible to achieve a new ecological balance without reducing the socio-economic complexity that informs advanced societies? Without the endogenous simplification of complexity through social conflicts and wars for the hoarding of limited resources, the reduction of freedoms and of collective services, or the simplifications imposed by exogenous environmental change such as the catastrophic reduction of natural resources? The data of the environmental accounting of the Western economies show that the issue which is irrevocable and urgent in the current model of growth is a quick and programmed abandonment of the energy produced by fossil fuels. As Figure 2 shows the absorption of carbon emissions occupies half of the global ecological footprint. The city, or, rather, the compact network of nodes (exactly the opposite of the peri-urban and rururban sprawl and of the diffused city, etc..), can play an important role in a new green or blue (Pauly, 2010) as some have suggested, economic scenario

a. In 2009, for the first time in human history, the urban population exceeded the rural one. The urban morphology is therefore the culmination of a process that tends to structure and complessify the world, the whole territory, and to respond to the increase of the global population still for a few decades. The need for that epigenesis is, as we have tried to demonstrate, that the functional and social complexity is based on the cities as dissipatave systems, namely ordered systems far from thermodynamic equilibrium and with high 'internal functional organization'. These organisms, the cities, are energy-intensive systems by their very definition. Complexity and order, in a process of further growth of the world population, do not require less (as many seem to believe) but more energy. The urgency of overcoming dependence on fossil fuels is thus reinforced.

b. In this process the morphological organization of the population plays a central role. This organization transforms the metabolism of demographic and social processes modifying reproductive forms, through the collapse of fertility rates and the emergence of (economic and cultural) behaviors that tend to reduce the P-factor of the I-PAT Equation.

c. The social space, especially in developing countries, continues to converge towards the urban nodes, as ordered and complex places which can diffuse prosperity and, consequently, a high life expectancy. An important role for the new balance and distribution of the network and poles will be played by the increase of the oil prices which constitutes the real engine (far more effective than the planning rules) to reduce the sprawl and generate strong centripetal forces.

d. At the same time in mature cities the trade-off between the rate of urbanization and CO_2 per capita define forms of savings, of optimization and economical use of resources. After an initial growth, necessary to the urban take-off, at high rates of urbanization, a decrease of the intensity per unito of GDP occurs. The final result is a growth of the environmental impact that tends to decrease with increasing of the urbanization. The hypothesis, which we tried to demonstrate, is that it is the urban organization in its maturity which generates relevant economies of scale and mechanisms that makes the dynamics of flows more efficient, through the Urban Environmental curves.

To conclude we can say that cities are systems of resilience to recover from a catastrophic failure that optimize the environmental metabolism (energy, space, etc..) and the socio-economic metabolism and create a relative delinking (not absolute) between economic growth and environmental resources. The general dynamics that synthesizes this complex process is indicated in figure 11: the urbanization does not stop the growth of the absolute environmental impact but establishes mechanisms of relative delinking that tend to decrease the intensity of this growth.

References

Bagliani M., Battaglia M., Ferlaino F, Guarino E., 2012, *Atlante della contabilità ambientale del Piemonte. Geografia e metabolismo dell'impronta ecologica*, IRES, Torino.

Bagliani M., Ferlaino F., Martini F., 2005, *Contabilità ambientale e impronta ecologica: casi studio del Piemonte, Svizzera e Rhône-Alpes/ Ecological Footprint Environmental Account: study cases of Piedomnt, Switzerland and Rhône-Alpes,* IRES, *Quaderni d'Europa 5*, Torino.

Bagliani M., Ferlaino F., Procopio S. (2002), L'Impronta Ecologica, in *Rapporto sullo stato dell'ambiente* 2002, Arpa-Piemonte, Torino, 320-324.

Barret J., Scott A., 2001, *An Ecological Footprint of Liverpool: Developing Sustainable Scenarios. A detailed Examination of Ecological Sustainability*, Stockholm Environment Institute and Sustainable Steps Consultant, Stockholm; in Maddison project: http://www.ggdc.net/maddison/maddison-project/home.htm (visited in October 2014).

Bolt, J. and J. L. van Zanden (2013). The First Update of the Maddison Project; Re-Estimating Growth Before 1820. Maddison Project Working Paper 4.

Brinkhoff Th., City Population, 2014, http://www.citypopulation.de. (visited in October 2014)

Bresso M., 1993, *Per una'economia ecologica*, La Nuova Italia Scientifica, Roma.

Camagni R., Gibelli M.C., Rigamonti P., 2002, *I costi collettivi della città dispersa*, Alinea ed, Firenze.

Cantore N., 2005, Obiettivi e metodi del delinking ambientale, in Ferlaino F. (Ed.), *La sostenibilità ambientale del territorio. Teorie e metodi*, Utet Libreria, Torino.

Chambers N., Griffiths P., Lewis K., Jenkin N., 2004, *Scotland's Footprint. A resource flow and ecological footprint analysis of Scotland. Report for Viridis*, Best Foot Forward Ltd, Oxford.

Christaller W., 1966, *Central Places in Southern Germany* (translated from *Die zentralen Orte in Suddeutschland,* 1933), Wiley, Chichester, England.

CIA, The World Factbook , 2014, https://www.cia.gov/library/publications/the-world-factbook/rankorder/rankorderguide.html, (visited in October 2014).

Granata E., Pileri P., 2013, Oltre la frammentazione: prospettive istituzionali per il governo dei territori alpini, in F.Ferlaino and F.S.Rota, 'La montagna italina. Confini, identità e politiche, Franco Angeli, Milano.

Daly H. E., 1981, *Lo stato stazionario* (translated from *Stady State Economics*, 1977), Sansoni, Firenze.

de Vries J., 1984, *European Urbanization 1500-1899*, Harvard University Press. Cambridge (Mass.).

Diamond J. ,2005, *Collasso* (translated from *Collapse. How societies choose to fail or survive*, 2005), Ed. Einaudi, Torino.

Ehrlich P.R. e J. Holdren, 1971, The Impact of Population Growth, *Science*, 171:26; 1212-1217.

Ferlaino F., Tiezzi E. (Eds.), 2001, *Analisi emergetica della sostenibilità ambientale della Regione Piemonte e del Comune di Torino*, IRES-Piemonte, Torino.

Ferlaino F., Lami I., 2009, Delinking territoriale: dalla decrescita economica allo sviluppo sostenibile, in: Borri d., Ferlaino F. (Eds.) Crescita e sviluppo regionale: strumenti, sistemi, azioni, Franco Angeli Milano, 91-115.

Georgescu-Roegen N., 1971, *The Entropy Law and the Economic Process,* Harvard University Press, Cambridge (Mass).

Høyer K.G. e Golden E., 2003, Househol Consumption and Ecologica Footprint in Norway –Does Urban Form Matter*?, Journal of Consumer Policy*, 26, 327-49.

International Monetary Fund, World Economic Outlook Database, October 2014; http://www.imf.org/external/data.htm ; (visited in October 2014).

Kuhndt M., 2005, Teoria e pratica del delinking del 'benessere' dall''uso della natura': Material Flow Accounting (MFA), Material Input per Service Unit (MIPS), Resource Efficiency Accounting (REA), in: F.Ferlaino (Ed.), *La sostenibilità ambientale del territorio. Teorie e metodi*, Utet Libreria, Torino, 177-197.

Latouche S., 2007, *La scommessa della decrescita*, Feltrinelli, Milano.

Launhardt W., 1885, Il fondamento matematico dell'economia politica, in: Bagiotti T. (Ed.) *Marginalisti matematici,* (1975), UTET Torino.

Maddison A., 2010, *Historical Statistics of the World Economy: 1-2008* in: www.ggdc.net/maddison/Historical.../horizontal-file_02-2010.xls, (visited in October 2014).

Maturana H., Varela F. ,1985, *Autopoiesi e cognizione. La realizzazione del vivente*, Marsilio, Padova.

Mazzanti M., Zoboli R., 2005, Waste indicators, Economic Drivers and Environmental Efficiency: Perspectives ano Delinking and Empirical Evidence for Europe, *Quaderno deit*, Working Paper 12/200, Università di Ferrara.

Meadows D. H., Meadows D. L., Randers J., Behrens W. W., 1972, *The Limits to Growth*., Universe Books, New York.

Morowitz H.J., 1979, *Energy Flow in Biology*, Ox Bow Press, Woodbridge.

Odum H. T., 2005, Un'analisi basata su 'emergy' ed 'emdollari', in: F.Ferlaino (Ed.), *La sostenibilità ambientale del territorio. Teorie e metodi*, Utet Libreria, Torino, 104-123.

OECD, 2001, *The World Economy: A Millennial Perspective*, OECD Development Centre, Paris.

OECD, 2002, *Indicators to measure decoupling of environmental pressure from economic growth*, OECD, Paris.

Pacholsky J., 2000, *The Ecological Footprint of Berlin (Germany) for the Year 2000*, thesis, Stirling University (Scotland).

Parsons T., 1965, *Il sistema sociale* (transleted from *The Social System*, 1951), Edizioni di Comunità, , Milano.

Pauli G., 2010, *Blue economy. 10 anni. 100 innovazioni. 100 milioni di posti di lavoro*, Edizioni Ambiente, Milano.

Prigogine I., Allen P.M., Herman R., 1979, *La Nuova Alleanza. Uomo e natura in una scienza unificata*, Longanesi, Milano.

Rosen, K. T., Mitchel Resnick ,1980, The size distribution of cities: An examination of the Pareto law and primacy, *Journal of Urban Economics*, 8:2, 165–186.

Thom R., 1985, *Modelli matematici della morfogenesi*, Einaudi, Torino.

Tiezzi E., Marchettini N., 1999, Che cos'è lo sviluppo sostenibile? Le basi scientifiche della sostenibilità e i guasti del pensiero unico**,** Donzelli, Roma.

UN, 2009, Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2008 Revision*, http://esa.un.org/unpp

von Weizsacker E. U., Lovins A. B., Lovins L. H. (1998), *Fattore 4 : come ridurre l'impatto ambientale moltiplicando per quattro l'efficienza della produzione*, Edizioni Ambiente, Milano.

World Data Bank, 2014, http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators#(visited in October 2014).

WWF, 2014, *Living Planet Report. Biodiversity, biocapacity and development,* http://wwf.panda.org/about_our_earth/all_publications/living_planet_report/ , (visited in October 2014).