MATERIAL AND ENERGY METABOLISM OF REGIONAL SYSTEMS: IMBALANCE AND WAYS OF ECOLOGICAL TRANSFORMATION

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Abstract: *From the standpoint of a systemic paradigm, a region represents a spatial nexus of abiotic, biotic, and social systems, which are in close coordination with each other and are constantly sharing material, energy, and information resources. The circular flow of matter, energy, and information between natural and social systems is termed as socio-ecological metabolism. By virtue of such an exchange, functionality and development of regional systems are maintained, and economic activities and formation of complex social structures are made possible.*

To meet the challenges of understanding regional systems in the context of global environmental change and achieving sustainable solutions for cities, appeals for interdisciplinary research are made. The article considers social and ecological system changes and transformations by drawing on resource users' knowledge and perceptions. Moreover, the attempts to demonstrate how social-

ecological transformations are being complicated by many factors beyond the control of any singular individual or a group, are made. Positive and negative outcomes are analyzed as well. The present research also carefully considers how the benefits of community-based governance initiatives are framed.

Key words: *socio-ecological metabolism, environmental change, ecological transformations, regional systems.*

JEL codes: *B4, R0, O2*

I. Introduction

Incessancy and sustainability of socio-ecological metabolism have guaranteed stable development of socio-ecological systems and preservation of a life-friendly environment on our planet for millennia. Since the latter half of the 20th century, there have been observed both acceleration of the processes of socio-ecological metabolism and rise in global energy and material consumption that were caused by improvement of the quality of life, boosted workforce productivity, reduced innovation and life cycles of manufactured goods. Increased discord in socio-ecological metabolism of regions is reflected in a bigger amount of domestic and industrial waste, greenhouse gas emission, destruction of ecosystems, and loss of regional biodiversity. Economic processes do not fit in with the natural circulation of matter and energy. This creates structural and functional shifts in regional systems, which ultimately lead to destruction of the whole system. Currently, the tasks are to achieve the balance of socio-ecological metabolism, to integrate and harmonize anthropogenic flow of matter and energy with the natural circulation, "to disconnect" economic growth and ecologic degradation of a territory. Solution to the existing problems can be made possible only by revolutionary changes of existing social practices and technologies, by transformation of economic, social, and political structures of a region. However, it is necessary to be careful about the ways we characterize the types of changes taking place in social-ecological systems (Blaikie, 1989). In this paper we define transformations as processes that involve fundamental reorganization of social and ecological structures, properties, and controls (Biggs et al. 2010, Chapin et al. 2010). The energy and material flows of a city are often described as urban metabolism, which links a city's ecology and economy. Urban metabolism is valuable in quantifying the city's use of natural resources but does not achieve a comprehensive, integrated analysis of the urban ecosystem. The concept of urban metabolism has been widely used to study energy and material

flows into and out of cities (Decker et al. 2000; Warren-Rhodes & Koenig, 2001). The extended concept of urban metabolism comprises four elements such as the total input (e.g., energy, material, money and information), distribution of the input within the city to drive urban functions, the total output (e.g., products, emissions and knowledge), and the regulating function that shapes such flows and distributions. Numerous empirical studies were conducted in cities worldwide (Boyden et al. 1981; Warren-Rhodes & Koenig, 2001). Adopting a comprehensive urban metabolism accounting approach, or focusing on individual substances of interest, and ranging from household to neighbourhood to city level, these studies revealed the large and increasing global impacts of cities.

Nevertheless, the concept has also been and the severe criticism and heated debate. Firstly, the researchers focused predominantly on quantifying various flows in and out of cities, without critical analysis of the concept (Lifset, 2004; Swyngedouw, 2006). Little attention has been paid to understanding how such approach and accumulated empirical evidences can contribute to the ecological insights of understanding cities as complex social-ecological systems. Secondly, it has become a widely accepted notion that more than an organism, cities are human-dominant, coupled, complex ecosystems (Grimm et al. 2008). To realize an interdisciplinary understanding of urban ecology, researchers need to emphasize the essential tenets of material flows analysis, view the city as an ecosystem, and use language that properly reflects current knowledge, theory, and conceptual frameworks in the foundational disciplines. More recent debates (Golubiewski, 2012; Kennedy, 2012) indicate there are still unresolved tensions and gaps between these two approaches.

The solutions must be complex and profound to grasp various levels of spatial interaction (local, regional, global).

2. Methodology and Data

To meet the challenges of understanding regional systems in the context of global environmental change and achieving sustainable solutions for cities and the planet as a whole, appeals for interdisciplinary research are made.

It is considered to be a promising tool to bridge the gap between ecological and socio-economic approaches to urban systems. Although readily adopted by some researchers, the relevance and appropriateness of urban metabolism remain largely unscrutinized (Burney, 2004; Swyngedouw, 2006). It is timely and necessary to undertake a thorough examination of its theoretical and practical aspects (Lifset, 2004; Swyngedouw, 2006).

Recent literature reviews report a growing number of applications of the industrial ecology model for material flow analysis in the design of the built environment. However, applications of material flow analysis in green infrastructure development are scarce. In this article we argue how the use of material flow analysis can inform decision-making towards more resource-efficient planning. What is more, the ecosystem service can enhance the impact of urban metabolism research on policy making and planning practice.

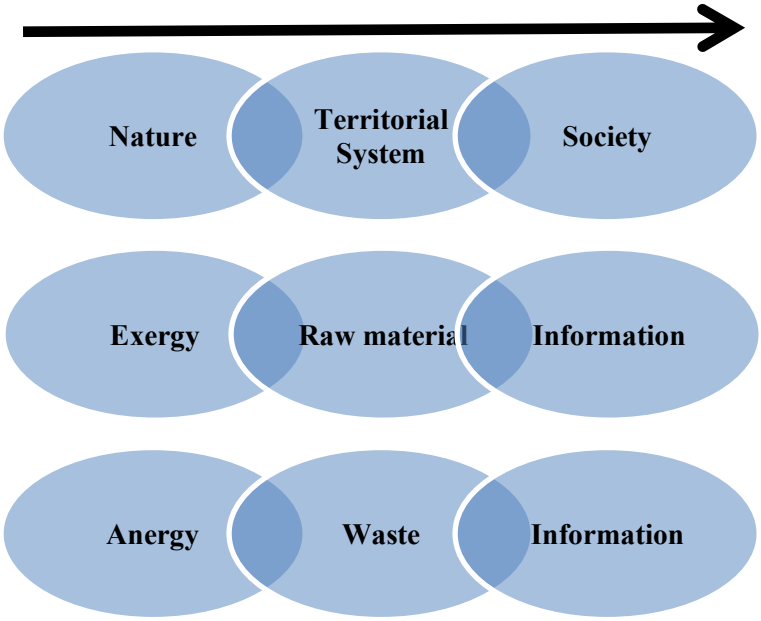
We conducted a literature review with the purpose of analyzing how the study of the eco-system services and benefits provided by green infrastructure can help identify its contribu- tion to a more energy-efficient socio-economic metabolism.

Regional material and energy metabolism pushed the boundaries of regional ecological systems long ago. It has resources of the entire world at its disposal.

Material and energy interactions between natural and social systems are presented in figure 1. In these relations, an important role is assigned to the transformation of useful energy (exergy) accumulated in nature into "dead" energy (anergy) by means of current human activities, also accompanied by the transformation of (raw) material into goods and, later, their utilization. Therefore, in light of the historical development of humanity, its geographical and technological expansion into the environment, energy and material capital of nature has been reduced; simultaneously, ratio of useless energy in the form of thermal and material waste into planetary spheres and ratio of growth of material waste have been increased; thus, leading to climate change and degradation of virtually all global ecosystems and biodiversity. As of today, natural raw materials are extracted from the Earth's interior in huge amounts annually, namely more than 135 BT, of which only 85 BT are used by humans per se [1].

In some countries, the level of material and energy consumption by their population goes beyond the boundaries of common sense: in Luxembourg – it exceeds 100 tonnes pp; in the UAE – 84 tonnes pp; in Singapore – 70 tonnes pp. (Ibidem). This being said, 99% of consumed resources in those countries are exported from other nations of the globe, mostly developing. In view of this, "imperial way of life" of population of the countries of global centre becomes the main problem of well-balanced regional metabolism. "Kinetic impressionism" or living conditions of the middle class of modern society, is based on the assumption that natural resources and their consumption are unlimited resulting in accumulation of regional anergy and enhancement of entropy processes that lead regional systems to degradation and self-destruction.

Fig. 1 Natural raw materials being in use



Source: made by the authors

In the context of this, the thoughts of W. Ostwald, a Nobel prize winner and author of the second law of thermodynamics, are introduced. In his philosophic works, he pointed out the necessity to restrain the entropy processes. He thought that the level of human progress is directly connected to the efficiency of transformation process from scattered to useful energy. The higher the efficiency, the lower the entropy processes, the higher the level of human progress (Ostwald, 1912). Stabilization of material and energy metabolism of a region and creation of a closed cycle of material and energy movement between natural and social systems are only possible by means of introduction of advanced technologies, change in production and consumer practices, moral responsibility for the preservation of regional and global ecosystems.

Recent decades have seen an expanding literature exploring urban energy and material flows, branded as urban metabolism analysis. However, this has occurred largely in parallel to the mainstream studies of cities as ecosystems. For instance, the main goal of the metabolic study of the southeastern part of the Calderona Mountain Range was to increase the sustainability levels of the region by optimizing the flows of materials and energy, as well as flows related to the transport of people within and in/outside the region (Perrotti, 2019).

A closer linkage and cross pollination between urban metabolism and urban ecosystem studies will advance our scientific understanding and better inform urban policy and management practices.

3. Results and Discussion

Today we recognize the vital necessity of transformation of regional systems toward sustainable material and energy metabolism between social and natural systems, transition to a new energy and material paradigm of the life of society to save the prospects of future development of all of mankind. An Austrian researcher, Prof. M. Fischer-Kowalski says that global civilization needs to transfer from the neoliberal economic regime based on the power of fuel mineral resources to a global community of stability based on the power of renewable resources and effective use of resources (Jaeger, 2016). Not only must the changes concern human's stand in respect to energy and resources consumption, but also include creation of brand new forms of human communities – in our case, brand new types of regions.

Achievement of sustainable socio-ecological metabolism in regions is currently a subject of heated scientific and public discussions. At this moment one can define three principal directions of discourse of sustainable development and transformation of socio-ecological systems. They are as follows: concepts of green economy, post-growth, and conviviality.

The core idea behind "green economy" is captured in eliminating antagonism between the development of economy and nature, achieving environmental goals by implementing new environmentally friendly and resource saving technologies into economic processes. According to a definition by The UN Environmental Programme (UNEP), green economy means a type of economic activity "that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (Bauriedl, 2017). In other words, "green economy" is qualitative economical growth, effective production with minimization of matter and energy cost, closed-loop economy with minimal emission and waste. Now "green economy" is a top-priority paradigm of the future economic development in countries across the globe. Currently observed tendency in ecological transformation of global economic management (renewable power generation, closed-loop economy, Industry 4.0, smart city, ecological transport, agriculture, etc.) are indicative of a new strategy of regional systems development.

"Green economy" is widely criticized as qualitative economic growth will not only fail to reduce the use of natural resources, but, conversely, will lead to even higher consumption and step up the pressure on ecological systems. By virtue of the rebound effect, every new level of technological advancement of products will require huge amounts of energy and material to replace the obsolete. In this way, currently promoted transition to electric transport and to "pure" energy sources, aiming to decarbonize economy and stabilize global climate, demands

such an expense of natural raw materials and energy for production that will make achievement of those goals impossible. Technological innovations by themselves will ultimately have no influence on regional consumption of natural resources at large (case in point is the "green modernization" of London) (Bauriedl, 2017). Sustainability requires mental transformation of a region: changes in consumer habits, production cutback, expansion of natural sites, refocusing of population's life attitudes from egoistic and consuming to social and moral. The main objective of regional development must be found not in economic growth and search of a niche in global division of labour, but in strengthening of regional resiliency (dynamic adjustment) or a territory's ability to resist internal and external crises (global climate change, geopolitical strikes, economic recessions), well-balanced and stable development of all the systems and structures of a region, which is only possible based on coevolution of natural and social systems.

The concept of conviviality (cohabitation) sees social unity, solidarity, and cooperation in a region as main factors of its stable development. While "green economy" requires "disconnection" of economy and ecology, the concept of conviviality, alternatively, strives to strengthen connections between humanity and nature, inside a community, and between communities (Vetter, 2015). In doing so, it tries to enhance socio-ecological awareness, suggests that further regional development is virtually impossible without decisive steps to "de-economize" the society, without implementation of such alternative (to neoliberal discourse) terms as cooperation, solidarity, mutual help, sufficiency, entirety, unity.

With the growth and consumption, it is difficult to think about the sustainability of the region‘s economies. What remains clear is that the region must not maintain the same economic structure based on cheap energy. Transport is one of the region’s main environmental energy problems, and it is not detached from the global supply of transport equipment. It should be stated that the resultant regional energy matrix is the unambiguous confirmation that the sector’s environmental sustainability cannot be left to the market.

The approaches point to where the construction of new forms of social organization should be heading, if a genuine option of sustainability is sought, while respecting Nature and allowing for the use of natural resources adapted to self-generation and regeneration. Nature, in short, must be left with the necessary capacity to recharge and repair so as not to deteriorate irreversibly as a result of human activity.

Proposals for a Green Economy might be implemented, such as in the form of the ‚Green New Deal‘ being advanced in Germany, based on a combination of the market, state control and social compromise. All these variants share one thing in common: a measure of faith in the

capitalist global market, in the existing political institutions, and in the technologies developed by capitalism for handling these multiple crises. This may well be different in different societies.

By contrast to these potential development options, the approaches subsumed under the heading of a socio-ecological transformation see the capitalist and imperial dynamics – including not only the relations of production, but also the living conditions of the people – more as the cause of the current problems than as their solution. Accordingly, more comprehensive policies have been formulated in this context.

The concept of a socio-ecological transformation is first of all a perspective that should not be misunderstood as being socio-technological. It must be substantively formulated, and must clearly shift the discourse, and must change institutional practices. It must be open to the reformulation of interests and values, for the settlement of conflicts, and for the critical consideration of experiences.

Therefore, today the key priority for civil society is to understand how to be organized in order to get more rooted in existing social movements and actors of society and make converge different powerful local struggles on energy issues at regional level to build a new political space to act on energy democracy issues for reclaiming the commons; as well as to develop a new convincing political narrative around energy, investment and infrastructure issues in order to get wider support among citizens.

Saving the planet for future generations means not only transforming the forms of production but also, rather, the transformation of social relations of domination and exploitation, which will also allow for the transformation of the way life is lived on the planet.

4. Conclusions

Over the last decades, socio-ecologic metabolism research has significantly contributed to an increased awareness of the environmental pressure associated with urbanization and to the discourse on more resource-efficient urban planning and design.

As a result, when it comes to the development of regional systems, there is a necessity in stabilization and sustainability of socio-ecological metabolism both inside a region and with its external environment. In our opinion, all the directions of ecological transformation of territories should be considered in strategies of social and economic development of the Russian regions. Combining introduction of advanced resource-saving technologies in all social spheres, simultaneous reinforcement of regional economic autarchy, region's manufactured and

food products and services self-sufficiency, abandonment of resource and energy intensive and ecologically dirty export production, as well as mainstreaming of convivial social practices (cooperation, self-organization) will establish the basis of a region's ecological transformation. This may be called a region of the future, with self-sufficient social and manufacturing system organically implemented into the environment in accordance with the strategy of coherent functioning.

The comparison of the energy metabolism can lead to a more appropriate management of energy use patterns and electricity generation mix in megacities, giving insights on strategies to improve urban energy efficiency and reducing environmental pressure of megacities.

To conclude, it matters whether metabolism is used or abused as there is a trend to connect ecology and economics within the organismal framework rather than an ecosystem one. Ecosystem ecology can thus be merged with established methodologies of material and energy flow analysis in order to transcend disciplines.

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