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Creation of the spatial model for sustainability: a physical economic approach

We interpret the potential of natural capital productivity in a spatial ecological social economic system (ESES) as the stock of free energy. According to the definition of entropy flow in an open system, the «negative entropy» inflow occurs into the Earth's biosphere, with the sustainability of the negentropic budget maintaining the living matter mass conservation law posited by Volodymyr Vernadsky. Introduction of spatial heterogeneity into the free energy definition reveals the non-additive property of its volume across spatial subsystems of the biosphere. This further emphasizes the conceptual shortcomings of stakeholder-centric and property-based sustainability decision-making models. Instead, trajectories of system's dynamics on different scales should become the subject of preventive decision-making and risk management by economic agents and regional stakeholders, acting in a multi-layered communication and coordination network with horizontal as well as hierarchical information and resource flows. The case of the Carpathian region is used to illustrate the substantive necessity and institutional prerequisites of a new spatial model for sustainable development.
Keywords: *natural capital, spatial ecological social economic systems, free energy, negentropy, preventive governance for sustainability.*

Problem statement. Analysis of the existing European governance mechanisms for macro-regional development suggests that their potential for projects' and programs' coordination across ecological, innovational and infrastructural dimensions of territorial cohesion and sustainability has yet to materialize [1]. Lack of sufficient attention towards spatial economic interactions of stakeholders in planning and operational processes should be noted as both a practical gap and a conceptual shortcoming in sustainability governance. The «communicative turn» in sustainability planning suffers from over-emphasis on procedural aspects at the expense of recognition of sustainability-related decisions on different governance levels as the value-based judgments [2]. This causes a number of tensions in sustainable development planning and governance, including the tensions between national and cross-border sustainability management, local and macro/mega-regional/global sustainability, including the cases described by Richardson [2]. These shortcomings of planning framework are further exacerbated by the dominant «three-dimensional» perspective of sustainability, which operationalizes it through distinct economic, social and environmental targets, including the UN Sustainable Development Goals[3]. Within this framework, the implied trade-offs between environment and development have posed practical obstacles towards implementation of sustainability targets in European countries [4].

Analysis of recent research. This necessitates a substantial revision of philosophic foundations [5] and methodology for operationalizing the sustainable development principles, particularly in the regional and spatial economic contexts. The proposed physical economic approach [6] to creation of spatially explicit sustainable development models for territorial units of different scales and organization levels is informed by novel insights of natural sciences as well as interdisciplinary systems studies.

It stems from the open nature of spatial socioecosystems that non-equilibrium processes subject to fluctuations play the predominant role in their development. This is where energy and matter exchanges take place, and where bioinformation, commodities and money traffic occurs. It is known that solar energy is the common source of energy for all processes on Earth which, being transformed, is manifested in the economic activity of a region and predetermines its working capacity. The Earth's surface energy budget of the region as a part of the terrestrial biosphere has its own thermodynamic regularity. This is why the ideas of the physical economic school founded by the Ukrainian scientist Serhiy Podolynsky must be laid as the foundation for fundamental research and modern economics for sustainable development. This provides the opportunity to combine physical processes with economic processes, methodologically prove the need for synthesis of natural and value parameters of solar energy and natural capital stocks preservation in processes of spatial economic activity.

Each spatial ecological social economic system (ESES) carries out productive work for economic consumption and reproduction of natural processes. This work is common for both social economic and natural components of the system. The potential of natural capital productivity in a spatial ESES can be interpreted as the stock of free energy (F) that, depending on the state of accumulated entropic potential according to Gibbs, or negentropy according to Schroedinger (σ), as well as actual entropy (S), forms the potential of its working capacity. The Earth system is out of thermodynamic equilibrium with outer space, but is maintained in a stable state by constant supply of solar energy (Q), which comes from the high-temperature source with $T_0 = 6000K$ and is dissipated into outer space at $T_1 = 300K$[7]. According to the definition of entropy flow (dS_e) in an open system [8], $dS_e = Q/T_1 - Q/T_2 < 0$, i.e. the «negative entropy» inflow occurs into the Earth's biosphere, with the sustainability of the negentropic budget [9] maintaining the biomass conservation law posited by Volodymyr Vernadsky [10]. According to him, «...chemical composition of the outer crust of our planet – biosphere – is completely influenced by life, i.e. it is determined by the living organisms. ... [T]he living organisms, i.e. the aggregate of life, transform this cosmic radiating energy into the Earth's chemical energy and produce the infinite variety of our world. These living organisms produce one of the most grandiose planetary phenomena... by their respiration, nourishment, metabolism and their reproduction, continuous use of their substance and, which is most important,.. by their birth and multiplication» [10].

The purpose of the paper. This paper outlines the conceptual foundations of the physical economic approach, and a multi-layered spatial sustainability model governed by it, using the case of the Carpathian macro-region.

Major research findings. Within the defined context, research and modelling of interdependencies between energy equivalent of natural capital and volumes of economic activity is very important. Within this context we can speak of ecological supply as the function of energy exchanging processes with natural environment [6]. The condition of sustainable development of a spatial ESES is then the maximal preservation of the volume of negentropy. Negentropy function of natural capital has aims and criteria different from the production function. It aims at the increase of not economic, but ecological wealth through preservation of negentropy budget in each ESES. Photosynthetic function of autotrophic organisms in the biosphere is of great importance, due to its role in production of the living matter as a self-regulator and supporter of life. This establishes the photosynthetic function of terrestrial ecosystems and its quantitative parameters as the primary spatial sustainability indicators, allowing consistent evaluation and management of natural capital [11]. For this reason, spatial negentropy function of natural environment preservation is necessary to integrate into the spatial economic analysis, placing sustainable restrictions on resource extraction and economic activity in the ESES. This leads to the modelling paradigm of economy built into the biospheric space, with terrestrial ecosystems as the core of an ESES subject to influence and disturbance by economic agents.

According to the above principles, spatial heterogeneity must be introduced into the basic physical definition of the natural capital productivity potential, free energy stock (F), which is identified as $F = U + pV - TS$, where U – internal energy of the system, p – pressure, V – volume, T – absolute temperature, S – entropy.

Due to simple additive nature of internal energy, volume, and entropy, heterogeneity should be introduced by allowing for differing temperature functions in each location of the biospheric space as a thermodynamic system, with the temperature function defined as partial derivative $U/\ S$. For a given «small region» in the biospheric space, we define $U_1/\ S_1 = T_1 = T'$, with $U_2/\ S_2 = T_2 = T$ for the rest of the space. It is evident that generally the biospheric free energy stock F is not equal to the sum of spatial subsystems' stocks F_1+F_2, and in case $T'>T$, $F > F_1+F_2$. This echoes the famous Aristotle's definition of a system as a whole larger than the sum of its parts and reflects the synergic effect of spatial subsystems within the biosphere. Furthermore, the volume of the synergy can be shown to equate $F - (F_1+F_2) = S_1(T'-T)$, i.e. to be dependent of the particular choice of a local subsystem with its entropy volume and temperature function. The proofs can be equivalently formulated for negentropy interpreted as Gibbs' entropic potential, identified, with the above notation, as $\sigma = (U+pV)/T - S$.

These simple relations have two crucial sustainability planning, programming and governance implications [12], which can be for the sake of discussion formulated in the form of the «no-go» theorems. First, there is no possible complete spatial allocation of the global natural capital. This is due to the synergic nature of the spatially determined free energy stocks, which makes neither global, nor decentralized governance sufficient for effective preservation of natural capital. Second, there is no possible depoliticized allocation of economic rights for the located natural capital fractions. This is due to non-additive properties of natural capital stocks of the territorial subsystems, which makes various delimitation, agents' identification and property distribution criteria applicable.

The outlined implications further emphasize the conceptual shortcomings of stakeholder-centric and property-based sustainability decision-making models. Particularly, contrary to the common assets trust model [13], de-emphasis of property rights management is seen as necessary in the future sustainable development frameworks and institutional projects, including World Environmental Constitution. Instead, trajectories of system's dynamics on different scales should become the subject of preventive decision-making and risk management by economic agents and regional stakeholders. The indicators of the spatial ESES dynamics can, according to the previously described physical economic principles, include photosynthetic productive function parameters, energy and entropy flows within and across the boundaries of terrestrial ecosystems, as well as informational functions of spatial resource extraction and economic activity distributions. A multi-layered communication and coordination network is one of the possible governance models within this general approach. Hierarchical as well as horizontal information flows can be applied, with a number of independent decentralized agents with their own domains of resources and targets of operating within the broader domain of a higher-level agent. This structure further necessitates strong institutional foundation rather than undermines the need for it, due to shift of focus towards agency from property rights allocation. The benefits of the proposed network model compared to both the global and the one-layer decentralized network governance include the improved monitoring and safety infrastructure, reduction of transactional and informational costs, and responsiveness to the above mentioned sustainability planning tensions as well as insights from the physical economic considerations. Resilience and economic efficiency of the layered network increase with the number of hierarchic levels and growing decentralization of a particular layer.

The complex institutional landscape of the Carpathian region, coupled with common environmental, sustainability and spatial development issues, can form the basis for this kind of heterogeneous network, which warrants further empirical and applied research in the region as the model ESES. The Carpathian regional unity has a number of aspects[14], including geographical, constituted by the Danube-Carpathian complex, hydrological, with the Tisa/Tisza basin as the major ecological pillar of the area, and bioecological, due to its ecological links as the Eastern part of the European Alpine region. The high share of forests and permanent grasslands conditions presence of the common land use patterns, despite the quite diverse spatial structure. Population of the macro-region amounts to app. 10 mln inhabitants, with recreational industry and agriculture prominent as the major economic sectors.

The common environmental and sustainable spatial development issues for the region [14] are caused, on the one hand, by common development trends of the Carpathian countries and country groups, as well as, on the other hand, by the above mentioned aspects of ecological, social and economic unity. The first group includes the common agro-environmental problems for the Western Carpathian countries, accompanied by the ongoing changes in agricultural production modes, as well as the risks of intensified spatial development associated with industrial and recreational prospects, particularly related to the Common Strategy of V4+2 countries' spatial development [15]. The second group of common sustainability issues includes flood prevention, toxic waste storage and river basin management in the Eastern part of the region, and, most importantly, biodiversity conservation in the face of intensified spatial development.

The institutional frameworks for the Carpathian region include the supranational European Union institutions, which exclude Ukraine but do involve the country into the mentioned macro-regional strategies and programs for the Danube region. The Western part of the region is mostly covered by the Visegrad Group international arrangements, the scope of which includes biodiversity conservation implementation issues and spatial development within and beyond the Group countries. The UNEP-backed Framework Convention on the Protection and Sustainable Development of the Carpathians, known as the Carpathian Convention, as well as the UNECE conventions package concerning the transboundary environmental governance issues, complete the international institutional level. The transboundary cooperation and coordination of the local administrations is to a large extent covered by the Carpathian Euroregion, while sub-national cooperation frameworks for territorial communities and local governments are country-specific. This institutional complexity, while beneficial for facilitation of the dynamic multi-layered decentralized communication for sustainability, requires further applied research to identify the optimal coordination, resource allocation and reporting paths for sub-national, cross-boundary, national, international and supranational agents.

Conclusions. As the first step towards elaboration and implementation of the proposed spatial model for sustainable development, an informal comprehensive framework could be developed for the Carpathian region, similar in its coverage to the existing European macro-regional strategies and capable of carrying out a subset of their functions for sustainability-oriented processes, projects and programs in the region. The framework should be targeted towards sustainability governance agents and stakeholders of various scales and levels, taking country-specific institutional discrepancies into account and including territorial communities, municipalities and sub-regional governments, as well as higher-level entities. It should elaborate the nature and substance of the sustainable development targets according to the described physical economic approach, and be accompanied by applied institutional analysis of cooperative and coordinative mechanisms for implementation of the targets, existing and prospective institutional tools for the respective process, project and program development, funding, implementation, monitoring and results dissemination.

This paper attempted to provide both methodological and practical account of the physical economic approach to spatialization of sustainable development, aimed towards a more scientifically justified, efficient and less politicized solutions of territorial sustainability issues. Informed by natural sciences, systems studies and philosophical developments, the methodology is capable of providing formal operational definitions of sustainability in complex ecological social economic systems, as well as identifying conceptual and practical shortcomings in widespread sustainable development governance frameworks, particularly stakeholder-centric and property-based approaches. Finally, more flexible and cost-efficient governance systems for spatial sustainability can be designed within this methodological domain.

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Гринів Л. С., Ходико Д. І. Формування просторової моделі для сталого розвитку: фізико-економічний підхід.

Будь-яка просторова екологосоціоекономічна модель виконує продуктивну роботу для економічного споживання та відтворення природних процесів. Ця робота є спільною як для соціально-економічної, так і для природної складової таких систем. Ми інтерпретуємо потенціал продуктивності природного капіталу у екологосоціоекономічних системах (ЕСЕС) як запас вільної енергії. Відповідно до визначення ентропійних потоків у відкритій системі, до земної біосфери відбувається приплив «негативної ентропії», причому стійкість негентропійного бюджету забезпечує додержання закону збереження біомаси живої речовини, сформульованого В.І. Вернадським. Умовою сталого розвитку просторових ЕСЕС, таким чином, є максимальне збереження обсягу негентропії наземних екосистем. Надзвичайно важлива роль належить фотосинтезу автотрофних організмів у біосфері завдяки його ролі у продукції живої речовини як чинника саморегуляції та підтримки життя. Це дозволяє визначити функцію фотосинтезу та її кількісні параметри як провідні індикатори просторової стійкості задля достовірного оцінювання та ефективного управління природним капіталом. Врахування просторової неоднорідності при визначенні вільної енергії дозволяє виявити властивість неадитивності її обсягів у просторових підсистемах біосфери. Відповідно, повний просторовий розподіл глобального запасу природного капіталу та деполітизований розподіл економічних прав користування локалізованими фондами природного капіталу є неможливими. Це додатково загострює концептуальні недоліки стейкхолдер-орієнтованих і заснованих на власності моделей управління сталим розвитком. Замість цього об'єктом превентивного управління та ризик-менеджменту еконономічних суб'єктів, об'єднаних у багатошарову мережу координації і комунікації, мають стати траєкторії системної динаміки різних організаційних рівнів. Ця схема гетерогенної мережі дає можливість підвищення територіальної опірності та економічної ефективності з точки зору транзакційних витрат, із зростанням кількості ієрархічних рівнів і ступеня горизонтальної децентралізації. Індикатори динаміки просторових ЕСЕС можуть включати параметри продуктивної функції фотосинтезу, внутрішні та транскордонні енергетичні та ентропійні потоки наземних екосистем, а також інформаційні функції просторового розподілу видобутку ресурсів та економічної діяльності. Для ілюстрації об'єктивної необхідності та інституційних передумов пропонованої просторової багаторівневої мережевої моделі управління сталим розвитком використано приклад Карпатського регіону. Спільні проблеми довкілля та розвитку регіону включають питання економічної реструктуризації, агроекологічні проблеми, відвернення природних стихійних лих, зберігання токсичних відходів та, найважливіше, збереження біорізноманіття в контексті інтенсивного просторового розвитку. Вони спричинені спільними тенденціями розвитку країн та груп країн Карпатського регіону, а також географічними, гідрологічними та біоекологічними аспектами регіональної єдності. Інституційна складність регіону, сприятлива для впровадження пропонованого управлінського підходу, вимагає подальших прикладних досліджень для виявлення оптимальних шляхів координації, розподілу ресурсів і звітності для регіональних, транскордонних, національних, міжнародних і наднаціональних суб'єктів задля розробки неформальної стратегічної рамки як першого кроку до впровадження пропонованого механізму.

Ключові слова: *природний капітал, просторові екологосоціоекономічні системи, вільна енергія, негентропія, превентивне управління для стійкості.*

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