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How to Develop a Sustainable Innovation Ecosystem? Example of ZalaZONE

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The purpose of the paper is to analyse the typical research trends along the current challenges of the social, environmental and business aspects of sustainability and discuss the issues of geographically concentrated, park-like innovation ecosystems. At ZalaZONE Park as a consciously built innovation ecosystem, sustainability aspects are organically integrated into its development and into the operation approach, giving the empiric case for the research question. The ZalaZONE Energy Ecosystem Program connects the subject of sustainability with the innovation ecosystem on system level through innovative technologies and future-oriented environmental initiatives in various energy projects. In connection with this, it is also investigated is how new technologies support and ensure the long-term sustainability of the innovation ecosystem, and how the features of this relationship can be interpreted. Since ZalaZONE Park shows the characteristics of complex systems, the overall framework of the analysis is provided by the ecosystem model previously developed by the authors and further developed in the present analysis. Such a model contributes to each development step of the innovation ecosystem for sake of balanced and sustainability-oriented growth. Finally, an aggregated system model was presented including aspects of sustainability, with particular regard to the characteristics of complex systems.

1. Introduction

The purpose of the paper is to show the approach for development of a sustainable innovation ecosystem, through the example of ZalaZONE Technology Park. The park has been created around the ZalaZONE Proving Ground which is a testing facility not only for classic vehicle dynamic validations but also for autonomous and automated vehicle solutions. The ZalaZONE innovation ecosystem is the result of the translational impact of the proving ground investment. In order to systematically manage the park long-term sustainability, a specific program was launched to support energy efficiency. In order to maximize impact of the specific energy projects, an ecosystem-level approach has been developed. This led to the need of integration of energy program as part of sustainability initiatives, innovation ecosystem development and the complete ZalaZONE park development concept. The current paper intends to give a comprehensive overview of this integrative approach.

The paper gives a theoretical overview of energy ecosystem concepts which are special forms of the ecosystems. The authors offer a summary to point out the need for complex systems perspective, beyond the usual general systems theory, due to the complexity of such ecosystems. The technology-related aspects are also given of the topic. Finally, the ZalaZONE energetics program status is presented.

The novelty of the work is the integrated any system-level perspective in the subject. Although ZalaZONE Park as innovation ecosystem follows the usual elements of such systems, but the proving ground and the technology park around it as catalysator give unique approach. Energy efficiency and emission reduction projects are not new in such ecosystems but integrating them into the whole ecosystem model is not evident. Putting all this into scientific system modelling gives the real novelty of the current work.

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2. Literature overview

Despite ongoing efforts, global energy consumption continues to rise, with fossil fuels still playing a dominant role. A clear trend today is the shift in energy system concepts: production is moving towards carbon-free solutions, and weather-dependent renewable energy sources are becoming increasingly prevalent. To make the energy sector more environmentally friendly, two things are needed: renewable energy producers and flexible energy solutions that enable the safe and regulated operation of energy systems. The concept of an energy ecosystem, as a system aiding sustainability, cannot be separated from its natural environment. An ecologist defines an ecosystem functionally as an energy-processing system (Reichle et al., 1975). The energetics of an ecosystem primarily consider the amount of energy used per unit area of the ecosystem. Efficiency is the measure that quantifies how this energy is transformed, allowing the calculation of the ecosystem's net energy productivity. The following analysis is cited because its research approach and findings can be well adapted to the system-oriented examination of the ZalaZONE energy ecosystem.

According to Liu et al. (2021), self-organization initially consists of interactions between disordered parts. In 1996, H.T. Odum extended the purely ecological meaning of self-organization, referring to the existence of an "energy hierarchy" in the transformation processes of the biosphere, including human systems and information. One of the main aspects of the energy hierarchy concept was the notion of energy quality, expressed in terms of the amount of available energy (existing energy = "exergy") required for production. The input-output ratio was called transformation, which could be applied to materials, energy sources, and information processes. The total available energy required directly or indirectly in the entire supply chain to produce an output product or service was termed "emergy." Another conclusion by Odum was that "transformation is only useful if it produces better quality and more benefits with less energy." The cybernetic nature of ecosystems and socio-economic systems provides another perspective, as discussed in Odum's article published in Science 30 y ago.

The immediate consequence is that higher-quality processes (such as electricity, information flow, and networks like the internet) come with enormous costs, supported by a much larger base of diverse and lower-quality resources, setting an upper limit to the growth of natural and human-dominated goods. The cybernetic nature of ecosystems and socio-economic systems provides another perspective, as discussed in Odum's article published in Science 30 y ago. Both natural ecosystems and socio-economic systems exhibit information flow, usage, and feedback in actions that coordinate, regulate, and control the transformation of matter and energy. Information, complexity (i.e., the presence of less structured systems), and emergy inputs are inseparably interconnected. The latest scientific literature on modeling energy ecosystems using systems modeling approaches highlights several innovative methodologies and frameworks. One such work by Ma (2023) states that the energy ecosystem is a highly complex and interconnected system encompassing stakeholders, technologies, infrastructure, regulations, and policies. This complexity necessitates an innovative approach to explore and introduce new technologies, regulatory frameworks, and business models.

Another significant contribution to this field is the development of hybrid modeling approaches that combine elements from different modeling traditions. For example, Subramanian et al. (2018) discuss the integration of Process Systems Engineering (PSE) and Energy Economics (EE) models. This combination enables a more holistic analysis of energy systems by capturing the technological characteristics of energy processes and the broader economic context, including stakeholder interactions and feedback effects. This hybrid approach is particularly useful in the optimal design and operation of flexible energy processes, sustainability analysis, and assessing the impacts of breakthrough technologies.

Agent-based modeling (ABM) frameworks also play a crucial role in modeling energy ecosystems. ABM is used to simulate complex systems with multiple autonomous agents, each representing different actors within the energy ecosystem. These agents interact based on defined roles and behaviors, allowing researchers to study the behaviors and interactions that emerge within the ecosystem. For example, an ABM framework developed for home charging systems for electric vehicles demonstrates how agent interactions can be modeled to understand the dynamics of energy distribution and consumption (Værbak et al., 2021). These recent developments in system modeling of energy ecosystems highlight the importance of integrating various modeling techniques to capture the complexity and interdependencies within systems. Such approaches enable more accurate predictions and better decision-making for sustainable energy management and policy development.

3. Elements of sustainable ecosystems

In today's economy that relies on knowledge, it is accepted by both governments and major industries that supporting innovation is crucial in improving a nation's competitive advantage. As companies attempt to create new products and services more quickly and efficiently, it becomes clear that one company alone cannot maximize its technological capabilities in isolation. In order improve their capabilities, companies must concentrate on collaboration with partners who offer complementary qualities, rather than focusing mainly on their internal resources. This method supports the establishment of networks of companies involved in innovative efforts. This tendency is driven by the large integration of contemporary information and communication technologies. Effective cooperation relationships are crucial for the rapid exchange of ideas and feedback, which is an essential component of flourishing industrial ecosystems (Tu and Wu, 2021; Farida and Setiawan, 2022; Krankovits et al., 2023, Shogenova et al., 2023). The collaboration of stakeholders in any ecosystem is the basis for operation of system elements through cooperations or usual relations. At sustainability-focused ecosystems, the relevance of collaboration has increased importance due to the interrelating aspects of sustainability. Neither the environmental nor the society consequences will not stop at borders of a player. Therefore joint efforts are needed in the ecosystem.

3.1 Advanced technological solutions for sustainability

An essential component of a sustainable innovative ecosystem is the use of advanced technical solutions. By integrating these technologies, businesses can get effective resource allocation and optimized workflows, which are crucial for the overall sustainability of the ecosystem (Javaid et al., 2022). The implementation of this technology improves operational efficiency and also decreases waste and preserves energy, making a substantial contribution to environmental sustainability. It promotes cooperation and the exchange of information among different entities, such as enterprises, academic institutions, and governmental organizations (Nizetic et al., 2020). The collaborative atmosphere develops a culture of invention and creativity, promoting ongoing enhancement and the creation of novel, sustainable solutions. This type of ecosystem supports the sharing of ideas and optimal methods, resulting in more efficient problem-solving and the promotion of sustainable development objectives (Furstenau et al., 2020).

3.2 Emerging technologies in sustainable innovation

Integrating modern technologies, such as artificial intelligence and renewable energy systems, are able to assist to the creation of a sustainable and innovative environment (Omri, 2020). The integration of IoT (Internet of Things) devices and intelligent infrastructure improves operational efficiency and reduces environmental consequences in diverse sectors (Bellini et al., 2022). For example, the integration of sustainable energy sources such as solar and wind power can significantly decrease carbon emissions and help in the prevention of climate change (Rehan, 2023; Razmjoo et al., 2021). Major improvements can be achieved through mixing renewable energy sources and smart grid technology, improving communication and collaboration among stakeholders, and optimizing resource use while minimizing environmental harm (Tang et al., 2021).

In addition, many other technical solutions are essential in enabling sustainable innovation ecosystems: Blockchain technology (Park and Li, 2021; Santhi and Muthuswamy, 2022), Edge computing technology (Santhi and Muthuswamy, 2022), Additive manufacturing (Drosatos et al., 2022), Biotechnology (Drosatos et al., 2022), Carbon Capture and Storage (Park and Li, 2021), Big data analytics and (Ostergaard et al., 2020), Real-time data analysis (Goel et al., 2020), Renewable energy sources (Naqvi et al., 2021), Smart grid technology (Meliani et al., 2021; Khan et al., 2022), sustainable innovations (Costa and Matias, 2020).

4. System model and its constraints

The ZalaZONE energy ecosystem is a new approach to the concept according to which sustainability plays an increasingly important role in the environmental optimization of the world. One of the main goals of the innovation ecosystem created in the immediate vicinity of the ZalaZONE automotive test track is to reduce harmful emissions with various energy solutions in the spirit of sustainability, which the ecosystem produces through various testing processes. The geographical overview of the complete ecosystem can be seen in Figure 1.

The generic system model of ZalaZONE energetics ecosystem is shown by Figure 2. The system model outlines the basic concept in between the input and output sides. On input side, various energy sources are supposed, which are available or might be used in the future. The output side shows the map of the diverse set of actual and potential users like the test track, the settled R&D centres, factories and social environment, with neighbourhood populations. The technical solutions are the connecting instruments between the input and output side while storing equipment and influencing factors make impact on behaviour and performance of the system.

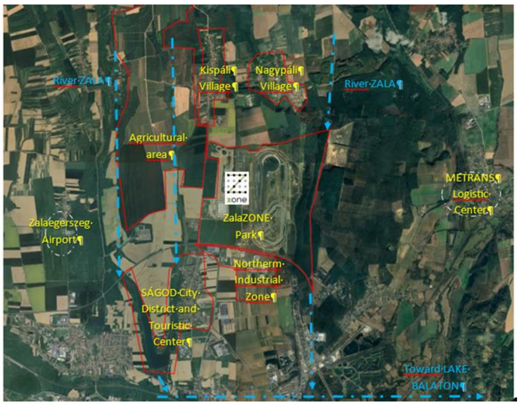

Figure 1: Overview of ecosystem around ZalaZONE proving ground

Main features of the technical aspects of the energetics ecosystem can be well-described by the usual system equations. There are many related research results in the theme of classic energetics system (or even energetics ecosystem) modelling. Nevertheless, the complexity of the current system approach of ZalaZONE Park specifically comes from two considerations. On one hand, the number of actors, interrelations, diversity creates an environment with large number of system elements, which, consequently, causes complexity of the related interrelations. Secondly, both the user side with several small organizations or single persons and the operators' nature with their human aspects conclude the importance of taking into account not only technical but soft factors also. This latter one leads to the level of society systems, beyond the purely materialized perspective. Therefore, modelling of the real system environment required implementation of further aspects different to the classis system theory.

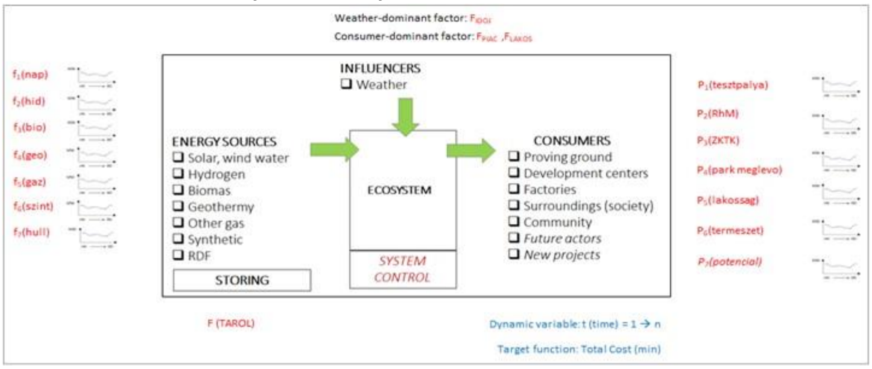

Figure 2: Generic system model of ZalaZONE energetics ecosystem

The general system theory could approach the system as the structure that converts inputs to the outputs. However, social systems, according to Kast and Rosenzweig (1972), may evolve beyond the boundaries of the systems, making the systems unpredictable. The typical irreversible processes of energetics firmly contribute to the unpredictable feature of an energetics ecosystem. This is one of the key features of the systems that needs a complex system point of view. The actors (either the users or the operators) of an energetics ecosystem always bear nature of human players, so the aspects of the social system have to be considered when defining the system model. Some authors – e.g. (Yawson, 2013) and (Yorks et al., 2012) pointed out that complex systems often show non-linear behaviours, and at these cases, application of general system theory is limited. For example, more sun-generated energy will result in direct positive impact on user consumption. Turner and Baker (2018) give a very detailed overview of complex adaptive system (CAS), highlighting – among others – the adaptive characteristics of such systems. Small change on input side can generate outputs difficult to foreseen, and the control of the system is challenging (Hanseth et al., 2010). Complexity theory addresses open systems instead of closed systems. This is important distinction between complexity theory and the usual systems theory approaches. Yawson (2013) identified three interrelating elements of complexity theory which could not be accounted for general systems theory: non-linear behaviour, chaos and unpredictability, adaptation.

As explained above, these characteristics are all present at energetics ecosystems, underlying the potential in complex systems theory so as to be an alternative for usual systems theory.

5. The ZalaZONE program

At the beginning of 2023, ZalaZONE Technology Park launched a comprehensive energy campaign aimed at facilitating significant green energy investments and energy R&D&I projects through various initiatives by 2030. ZalaZONE Technology Park aims to be a leading project site for a carbon-neutral and energy-efficient industrial park and energy community. A proposal incorporating a 5.4 MW grid-connected solar power plant combined with an energy storage system has been introduced with the aim of supplying electricity to consumers within the industrial park through a PPA agreement. Several options for the energy storage system were evaluated, resulting in the installation of a 10 MW/20 MWh energy storage facility. The primary goal of the proposed investment is to participate in the balancing services market and manage energy consumption within the Technology Park (to support the production and consumption scheduling). An integration plan has been formulated to combine the energy storage, solar panels, and local enterprises within the industrial park under an aggregator framework. The energy storage system's aFRR certification will be attained via the aggregator. The aggregator's registration process has been finalized. Initiatives are in progress to establish a small-scale energy community involving the ZalaZONE Technology Park, Zalaegerszeg, and the neighboring areas - a concept presently in the developmental stage. In addition, efforts are being made to establish a regulatory sandbox to facilitate the early implementation of the upcoming EU electricity market regulations. The "54/2024 (III.6.) Government Decree on the different application of Act LXXXVI of 2007 on electricity during the state of emergency" also covers the project proposals of the ZalaZONE Technology Park. As a result of this Regulation, the joint application submitted has been declined, and a grid connection permit cannot be obtained until 2030. Consequently, the energy strategy of the ZalaZONE Park will have to be reassessed based on new principles. The above-mentioned systems will be installed as reconfigured, off-grid, or 'echo-watt' systems. Initially, a 200 kW photovoltaic system will be put into operation and in the initial stage, a 200 kW photovoltaic system deployed.

6. Conclusions

In conclusion, a good innovation ecosystem is mostly dependent on the integration of cutting-edge technical solutions and efficient cooperation amongst different stakeholders. Modern technologies that improve operational efficiency, lower environmental effect, and promote an innovative and creative culture include artificial intelligence, the Internet of Things, blockchain, edge computing, and renewable energy systems. The case study of ZalaZONE shows how these technologies may be used by a well-designed innovation ecosystem to accomplish sustainability objectives. Successful application of these ecosystems requires on ongoing cooperation between government, business, and academia as well as a thorough knowledge of the many interactions within the system. We can build robust, long-lasting ecosystems that can meet the problems of the future by adopting these cutting-edge solutions and encouraging cooperative settings.

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