Kielnarowa Review, (2024), 1, 72-84

Mathematical Thinking for Sustainable Development

Małgorzata Gosek

Introduction

The Earth is on the verge of losing stable and human-friendly living conditions. Human activity, which is degrading the environment on a planetary scale and causing climate warming, is bringing about this.

For over 3 billion years, interactions between the geosphere and the biosphere controlled global environmental conditions. The state of the Earth's system changed due to forces caused by external disturbances or internal processes within the geosphere or biosphere. Today, however, there is a new force—human activity—and the anthroposphere has become an additional functional element of the Earth system, capable of altering its state (Richardson et al., 2023).

The climate and environmental crisis requires swift and effective action—transforming the economy and businesses, enacting wise legal regulations, and, most importantly, driving social change towards responsible consumption and pro-environmental attitudes. However, knowledge about the environmental crisis does not sufficiently permeate social awareness. While some improvement is visible, much must be done (Stefaniuk, 2021). People struggle to access accurate information amidst the flood of ecological fake news, and they have difficulty understanding how their daily choices and activities contribute to environmental degradation, as well as the consequences this brings for them and the planet. Environmental education, which is insufficient in schools, does not help (Gosek, 2023).

The implementation of the concept of sustainable development, which emerged as a remedy for the crisis and was intended to lead to economic and social changes, continues to face numerous obstacles despite the efforts of communities and states. The ease with which disruptions in action are justified by external factors, such as the COVID-19 pandemic, is noticeable (Council of Ministers..., 2023, pp. 13-14). It also seems that there is a lack of understanding of the interdependencies between the Sustainable Development Goals. Recognising these connections and strategically planning for them would enable better control over their implementation. However, this requires specific cognitive competencies that allow these relationships to be decoded.

This paper aims to demonstrate how mathematical and systems thinking can support the resolution of the environmental crisis and enhance the effectiveness of implementing sustainable development principles. The study employs an analytical-synthetic method based on literature and reports. The starting point is a synthetic overview of the contemporary climate and environmental crisis and the challenges in implementing sustainable development. In the next step, systems thinking and mathematical thinking are applied to understand the causes of the crisis and the barriers to sustainable development implementation. The analysis shows that effectively overcoming the crisis requires understanding the complexity of systems (natural and their connected systems—social and economic) and the intricate interactions between the Sustainable Development Goals. For this, systems thinking, supported by mathematical thinking, is essential. Developing these competencies is therefore crucial in education for sustainable development and is one of the conditions for successfully addressing the climate and environmental crisis.

The Contemporary Climate and Environmental Crisis

Anthropogenic pressure, mainly through the emission of greenhouse gases, has led to the warming of the atmosphere, oceans, and land. Between 2011 and 2020, Earth's surface temperature rose by 1.1°C above levels recorded in 1850-1900 (IPCC, 2023, p. 4). Future projections leave no illusions that this process will continue. In the five greenhouse gas emission scenarios analysed in the IPCC report, the year 2100 is expected to increase the global surface temperature from about 1.4°C to over 4°C above pre-industrial levels (IPCC, 2023, p. 7).

However, climate change is not the only concern. Equally troubling are the data on environmental degradation. Forty per cent of soils are severely degraded, and the loss of arable land occurs over 100 times faster than its natural formation (Hickel, 2022, p. 19). Agriculture alone is responsible for 80% of global deforestation, 70% of the decline in biodiversity in terrestrial ecosystems, 50% of the loss in freshwater biodiversity, 70% of freshwater use, and 29% of greenhouse gas emissions (Kramarz, 2022, p. 436). From agricultural lands, 89 million tons of synthetic fertilisers not absorbed by the soil flowed into water bodies out of the 200 million tons applied, destroying the environment. Additionally, 4 million tons of toxic pesticides are used annually to protect crops and orchards from weeds and pests that harm plants, insects, birds, and human health (Pomianek, 2023; Pomianek, 2024).

The ongoing changes are vividly illustrated by the concept of Planetary Boundaries, which view the planetary system as an integrated socio-ecological system consisting of nine processes responsible for the stability and resilience of our planet. All of these processes are critically affected by human activity. Recent data show that six of these processes have already exceeded safe boundaries. Besides climate change, they include biosphere integrity, novel environmental entities, biochemical flows, land system change, and freshwater use. Ocean acidification remains within the safe zone (though close to the limit), along with aerosol loading and stratospheric ozone levels (Richardson et al., 2023). The Planetary Boundaries model highlights that exceeding any individual boundary destabilises the entire system and underscores the importance of the feedback loops. However, it does not account for the socio-economic factors, processes, and structures driving the ecological crisis. Therefore, an alternative concept introduces the notion of social boundaries, defined by societies as self-imposed limits and conditions for “a good life for all” (Brand et al., 2021, pp. 265, 268).

The literature calls for humanising and socialising the discussion of the environmental crisis and drawing on expertise from fields like degrowth ecological economics, which offers concrete proposals for transformation (Hickel, 2021; Raworth, 2021; Bińczyk, 2023, pp. 14-

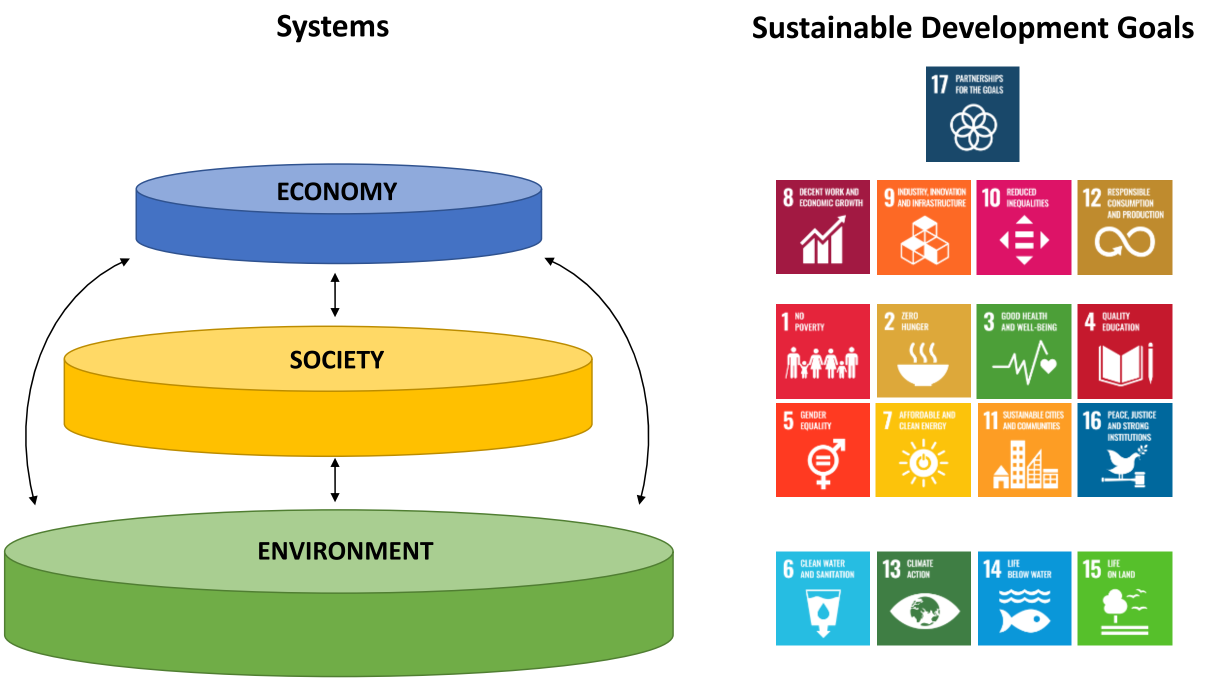
15). These approaches emphasise the need to recognise the interconnections between environmental, social, and economic spheres to understand the root causes of the crisis.

Sustainable Development as an Idea and Goal

Environmental problems and the need to solve them were recognised many years ago. In 1987, the World Commission on Environment and Development stated in its report: “At the current level of civilisation, sustainable development is possible, meaning development in which the needs of the present generation can be met without compromising the ability of future generations to meet their own needs.” Since then, sustainable development has become a subject of academic interest and an idea that has begun to be implemented.

In 2015, the United Nations (UN) adopted the 2030 Agenda, which includes 17 Sustainable Development Goals (SDGs) to be achieved by 2030 (www4). These goals relate to three systems: environment, society, and economy, outlining a vision of a healthy natural environment (Goals 6, 13, 14, and 15), a prosperous, equal, and inclusive society with access to quality education for all, living in health and peace (Goals 1, 2, 3, 4, 5, 7, 11, and 16), and an economy based on responsible consumption and production, sustainable industrialisation, stable infrastructure, with no inequalities between countries, and decent work for all (Goals 8, 9, 10, 12)—all of this supported through partnerships and cooperation (Goal 17) (Figure 1).

Figure 1. Sustainable Development Goals concerning the natural, social, and economic environments.



Source: Own work based on online sources (www3; www5).

Sustainable development has been incorporated into the Treaty on European Union and the 2001 EU Sustainable Development Strategy. In subsequent years, the 2030 Agenda goals were aligned with European strategies, European Commission priorities, and other documents. The European Green Deal (2019), the EU's new economic strategy, aims for the EU economy to be climate-neutral, resource-efficient, and circular by 2050 (www1; European Commission, 2019).

Global and EU strategies and regulations have been translated into national frameworks. In Poland, the response to the 2030 Agenda was the adoption of the Responsible Development Strategy (Ministry of Development, n.d.).

The implementation of the SDGs has also reached the level of businesses, which significantly impacts environmental and social issues. This shift is driven by enforcing regulations, pressure from conscious consumers, and growing awareness among corporate leaders.

The effectiveness of implementing the 17 SDGs is continuously monitored globally, at the European level, and within individual countries, with indicators made available to the public (Sachs et al., 2023; Council of Ministers..., 2023; www1; www2). Businesses' sustainability reporting (ESG reporting) is becoming increasingly widespread, although it is not yet mandatory in all countries. A notable example of mandatory reporting is in the EU, where in 2022, a directive was introduced requiring certain entities (with an expanding scope) to include information on environmental, social, and governance issues in their business reports, following common European sustainability reporting standards, known as ESRS (Directive of the European Parliament…, 2022). These regulations are driving profound changes in corporate thinking and operations. Moreover, an approach based on transparency throughout the value chain will also compel changes among suppliers and distributors (Redqueen, 2023, p. 33). These changes are becoming increasingly visible and will continue to expand.

Sustainable Development Goals – Interconnections and Consequences

In pursuing Sustainable Development Goals (SDGs), it is essential to recognise that they offer a holistic and multidimensional view of development and cannot be treated as standalone objectives. They must function as a system of interlocking gears and should not be seen as an additive structure but as a system of synergistic reinforcement (Pradhan et al., 2017, p. 1177). Only by achieving all goals can the global community realise the expected outcome.

However, this approach to the SDGs is not universally adopted. Some awareness of the interconnections between the goals exists among policymakers and implementing bodies. For instance, in a report on public administration activities in Poland, the connections between the main goal and other goals were identified (Council of Ministers..., 2023, pp. 148–156). The situation is less consistent in business operations, where goals are often pursued selectively without more profound reflection.

A lack of clearly defined relationships between goals and an insufficient understanding of these interconnections leads to incoherent policies during implementation (Costanza et al., 2016; Nilsson et al., 2016; Le Blanc, 2015). Analyses of SDG interactions and identified synergies (positive correlations between pairs of indicators) and trade-offs (negative correlations) reveal that the success of the SDG agenda will largely depend on the ability to harness synergies and address the trade-offs that obstruct goal achievement. Moreover, ensuring that these trade-offs do not become structural obstacles or, if necessary, implement more profound structural changes (Pradhan et al., 2017).

Ecosystem as a Complex System and Interconnected Systems

In addition to recognising the relationships between the SDGs, it is equally important to diagnose the interconnections within the ecosystem and the links between the ecosystem and the social and economic systems.

A natural ecosystem is a complex system consisting of many interconnected elements that interact non-linearly, leading to emergent properties and behaviours in the system as a whole.

Complex systems are characterised by non-linear behaviour stemming from long and feedback-driven chains of cause-and-effect relationships due to interactions among their elements. They have the capacity for self-organisation and evolutionary potential, dependent on the strength of internal interactions and interactions with the environment. In stable, unstable, and borderline states, complex systems can exhibit three qualitatively different types of behaviour: small changes or no changes, disorganised changes, and patterned behaviour that is unpredictable in detail. Complex systems demonstrate emergent behaviours—properties of the whole system that do not directly result from the behaviour of individual elements but are outcomes of the interactions and organisation of these elements. Some systems can adapt (Balcerak, 2020, pp. 6–7).

The ecosystem can be considered complex for several reasons. It includes numerous elements (plants, animals, fungi, bacteria, etc.) with diverse functions and roles. A network of interactions exists among species and organisms (e.g., food chains, symbiotic relationships). Actions and interactions between organisms lead to the emergence of new features and behaviours (e.g., self-regulation capacity). The ecosystem is dynamic and subject to changes due to shifting environmental factors (e.g., climate change). The processes occurring in the ecosystem are non-linear, and their outcomes are difficult to predict.

Understanding the ecosystem requires an interdisciplinary approach and analysis at different levels, from micro-scale (inter-organism interactions) to macro-scale (global processes).

A notable example illustrating the difficulty of understanding ecosystems is the Biosphere 2 project (1980s–90s), aimed at creating an alternative to Earth's biosphere. A complex was built in the U.S. over 12,700 square meters in size, including a tropical forest, mangroves, savanna, and ocean system. Eight people were supposed to survive there for two years without external contact, self-sufficiently producing drinking water, breathable air, and food. The project failed. Problems arose with food supply; all bees and hummingbirds went extinct, nematodes and mites attacked the plants, cockroaches multiplied, and the climate collapsed. The inhabitants had to rely on food supplies and oxygen from outside (Borejza, 2023). This failure starkly demonstrated how little humans know about the complexity of Earth's ecosystem.

In addition to understanding the ecosystem, it is equally important to grasp its connections with the social and economic systems. Climate change, through its impact on agriculture—the primary source of national income for underdeveloped countries—contributes to increased social inequalities. Global warming has caused a 25% increase in inequality between countries over the past half-century (Diffenbaugh & Burke, 2019). Climate warming also raises sea levels, increasing risks for many island nations, and causes droughts and limited access to freshwater (Budziszewska et al., 2021, p. 211). Consequently, it influences migration patterns. Between 2016 and 2021, more than 43 million children and young people in 44 countries worldwide were forced to leave their homes due to floods, droughts, or wildfires, and over the next 30 years, more than 100 million are expected to be displaced for similar reasons (Sieradzka, 2023). Regions expected to face food shortages and water-related problems include South Asia, Central and Southern Africa, and South America (Budziszewska et al., 2021, pp. 211–213). When paired with demographic forecasts that predict five of the ten most populous countries in the world in 2100 will be in Africa and four in Asia, the scale of migration becomes easy to imagine (Buchholz, 2020).

Climate warming also affects the economy. It contributes to the food crisis. A 1°C rise in global temperatures results in a 10% decline in crop yields, which, given current trends, will lead to a 30% reduction in global harvests within this century (Hickel, 2021, p. 29). It has caused growing economic losses due to extreme weather events ($264 billion in 2022) and heat exposure (490 billion lost potential working hours worldwide in 2022) (Karaczun, 2023).

Understanding the interconnections between the ecosystem and other systems is critical to effectively implementing sustainable development. However, it remains a significant challenge.

Systems Thinking

Systems thinking helps in understanding complex systems. This approach focuses on analysing and comprehending complex systems as a whole rather than merely as a collection of separate elements. Its main objective is to study the interrelationships, patterns, and processes within systems to understand better how they function and to predict how they will respond to changes. A systems perspective allows placing a specific event in a broader context, embedding it in time and space, defining the problem dynamically, and thus gaining deeper insights (Kronenberg & Bergier, 2010, p. 48).

The critical elements of a systems approach are the multitude of factors, mutual interconnections, and the closed chain of causes and effects, which form what are known as feedback loops. These can be reinforcing, driving system growth, causing rapid negative changes, or balancing and stabilising the system (Rokita, 2011, p. 90).

Systems thinking is beneficial not only for understanding ecosystems but also for implementing sustainable development principles. An example is the circular economy (CE)—an idea in which materials, components, and products (MCP) should be designed and produced to be restored, maintained, and redistributed within the economy for as long as possible in terms of environmental, technical, social, and economic factors (Hahladakis & Iacovidou, 2019). For successful implementation, it is essential to move away from a waste-focused system, where the quality of MCP degrades as they flow through production, consumption, and management systems, and to adopt a holistic approach that ensures solutions in one system (or system point) do not cause problems in another system (or another point of the same system). This is achieved through systems thinking, which examines subsystems' internal and external elements critical to transitioning to a circular economy and their interconnections. This approach allows for understanding how the resource recovery system evolves culturally, temporally, and spatially (Iacovidou et al., 2021, p. 24800).

Mathematical Thinking as a Complement to Systems Thinking

Systems thinking can be effectively supported by mathematical thinking, the ability to reason, analyze, and solve problems using mathematics. Mathematical thinking includes formulating logical arguments, thinking abstractly, and creating models and strategies for solving mathematical problems. Some of its manifestations include the ability to recognise and utilise analogies, schematisation and mathematisation, defining and interpreting definitions rationally, deduction and reduction, encoding, constructing, and using mathematical language rationally, as well as algorithmisation and the rational use of algorithms (Juskowiak & Mleczak, 2023, p. 73).

Mathematical and systems thinking share a similar approach to analysis, modelling, and problem-solving, and their integration can be highly effective. These approaches can complement and reinforce each other (Table 1).

Table 1. Systems Thinking and Mathematical Thinking – Complementary Approaches

Area	Systems Thinking	Mathematical Thinking
Problem-Solving	It helps identify general problems and interactions between system elements.	They are used to develop strategies for solving mathematical problems.
Understanding and Analyzing Complexity	Studies the relationships and interactions between system elements.	Provides tools to describe and analyse structures and processes.
Providing Abstract Models and Patterns	Provides systems thinking models (e.g., flow diagrams) to study interactions.	Provides mathematical structures (e.g., equations, functions, graphs) to describe phenomena and relationships.
Data Analysis and Drawing Conclusions	It helps identify patterns and trends in data and understand their causes.	Provides statistical, algebraic, and numerical techniques for data analysis.

Process Optimization and System Design	It helps design efficient, sustainable, and productive systems.	Provides tools to optimise functions and processes.

Source: Own work, partially based on the literature (Kronenberg & Bergier, 2010; Meadows, 2022).

Mathematical thinking thus aids in solving problems within complex systems. It can also help understand ecosystems, social and economic systems and their interactions.

The Need for Education for Sustainable Development

The need for a transformation in thinking about sustainable development has been identified as a crucial factor for successfully implementing the 2030 Agenda (Council of Ministers... 2023, p. 12). It is essential to understand the natural, social, and economic environments in which we live, the causes of the crisis, and the essence of the sustainable development concept being implemented so that actions taken can genuinely address the root causes of the problem. There is a growing need for a broader perspective, an understanding of system complexity, the ability to diagnose connections, and a critical view of reality. However, increasingly complex problems are emerging, while the ability for logical and analytical thinking, especially among the younger generation, is unfortunately not improving.

In ongoing discussions about education for sustainable development, the need to account for the complexity, ambiguity, and interdisciplinary nature of the problem of sustainable development has been emphasised. Education focused on multidisciplinarity, critical and systems thinking, and interdisciplinary skills have been proposed (Warburton, 2003). Suggestions have included using network science through peer-based, problem-oriented, and transformative approaches to learning (Weber, 2021). The need for holistic education that considers all aspects of human functioning in the socio-natural reality has also been highlighted (Mróz & Ocetkiewicz, 2019, p. 39). Proposals have been made to introduce an intermediate stage between the "how things are" knowledge phase and practical action – a stage of "broadening the mind," a kind of "mental gymnastics," which would include not only seemingly obvious things and phenomena but also methods of analysing phenomena based on comparisons, seeking relationships and analogies between seemingly distant events and facts (Górniak et al., 2003).

Thus, education for sustainable development should involve shaping mathematical and systems thinking. However, studies among teachers show that it is primarily associated with environmental protection. Systems thinking is not recognised at all as a critical competency in education for sustainable development, even though its development is a fundamental premise of the harmonious development concept (viewing the world as a complex system of interdependencies) (Mróz & Ocetkiewicz, 2019, p. 42).

Summary

Human activity has led to climate warming and environmental degradation on a planetary scale. Understanding the causes and mechanisms of these changes is a challenge for researchers and every individual. The adverse effects accelerate and reinforce each other when time runs out. Scientific knowledge is needed to design ways out of the crisis, and social awareness is required to change people's attitudes and pressure decision-makers, urging them to act. However, understanding the nature of the crisis requires delving into the complex structure of systems.

The same applies to attempts to implement sustainable development and achieve the 17 Goals. Despite determination, obstacles arise in implementation. This happens because the 17 Goals and their related 169 targets form one global objective for humanity, with many internal connections, the understanding of which is not simple. However, such understanding is necessary for success.

Understanding the complexity of systems is essential to effectively addressing the crisis, and for that, systems competencies and mathematical thinking are necessary.

Systems and mathematical thinking are pathways to understanding ongoing processes, the complexity of systems, and their interactions, as well as identifying the causes of climate and environmental crises. They are tools for planning and managing the implementation of Sustainable Development Goals and raising awareness of their interconnections. Systems and mathematical thinking should be mandatory education components for sustainable development, whether in school, university, or professional training.

However, rational arguments alone are not enough for success. Knowledge does not always lead to action. Emotions are needed – the experience of nature, a sense of connection, and the pursuit of harmony. There must also be a sense of responsibility for one's children and grandchildren for future generations. Emotions and responsibility will translate into commitment and determination in action. There needs to be a return to values, transmitting them at home, building education around them in schools, and making them the core of business practices.

Without raising the level of education, society will not be able to push the political class to take necessary action, and systemic changes are essential if humanity is to begin emerging from the climate and environmental crisis.

References

Documents and Legal Acts:

Directive (EU) 2022/2464 of the European Parliament and Council, https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX:32022L2464 (accessed: April 28, 2024).

European Commission (2019). Communication from the Commission. European Green Deal. https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX:52019DC0640 (accessed: February 25, 2024).

Ministry of Development (n.d.). Agenda 2030 for Sustainable Development – Implementation in Poland, https://www.un.org.pl/files/170/Agenda2030PL_pl-5.pdf (accessed: February 25, 2024).

Council of Ministers of the Republic of Poland (2023). Implementation of Sustainable Development Goals in Poland. Report 2023, https://www.gov.pl/web/sdg-portal-wiedzy/realizacja-celow-zrownowazonego-rozwoju-w-polsce-raport-2023 (accessed: April 20, 2024).

Redqueen, S. (2023). ESG Reporting Guidelines. A Guide for Companies, https://www.gpw.pl/pub/GPW/ESG/Wytyczne_do_raportowania_ESG.pdf (accessed: November 21, 2023).

Books and Papers:

Balcerak A. (2020), Akceptacja złożoności w uczeniu się organizacyjnym, „Zeszyty Naukowe Politechniki Poznańskiej. Organizacja i Zarządzanie", 81, s. 5-20, doi: 10.21008/j.0239-9415.2020.081.01.

Bińczyk E. (2023), *Jaka sprawiedliwość w epoce antropocenu? Wstępne rozstrzygnięcia i wybrane trudności*, „Postscriptum Polonistyczne" 2023, *32*(2), s. 1-19, https://doi.org/10.31261/PS_P.2023.32.03

Borejza T. (2023), *Próbowali ujarzmić prawa natury. „Dusiliśmy się i głodowaliśmy!"*, https://smoglab.pl/tworcy-biosfery-2-dusilismy-sie-i-glodowalismy/ (14.01.2024).

Budziszewska M., Kardaś A., Bohdanowicz Z. (2021), *Klimatyczne ABC*, Warszawa, https://www.wuw.pl/product-pol-18569-Klimatyczne-ABC-Interdyscyplinarne-podstawy-wspolczesnej-wiedzy-o-zmianie-klimatu-PDF.html (27.04.2024).

Brand U et al. (2021). *From planetary to societal boundaries: an argument for collectively defined self-limitation*, "Sustainability: Science, Practice and Policy", 17:1, s. 264–291, DOI: 10.1080/15487733.2021.1940754.

Buchholz K. (2020). *In 2100, Five of the Ten Biggest Countries in the World Will Be in Africa*, https://www.statista.com/chart/20298/most-populous-countries-in-the-world-in-1950-2020-and-2100/ (14.04.2024).

Costanza, R. i in. (2016), *Modelling and measuring sustainable wellbeing in connection with the UN Sustainable Development Goals*, "Ecological Economics", t. 130, s. 350–355.

Diffenbaugh N. S., Burke M. (2019). *Global warming has increased global economic inequality*, "Social Sciences", April 22, 2019, 116 (20) 9808-9813, https://doi.org/10.1073/pnas.1816020116.

Gosek M. (2023). *Kryzysu klimatycznego w polskiej szkole nie ma*, https://zielonyblog.wsiz.edu.pl/kryzysu-klimatycznego-w-polskiej-szkole-nie-ma/ (27.04.2024).

Górniak L., Mudyń K., Budzyna-Dawidowski P. (2003), *Nauczanie myślenia systemowego na uniwersytecie, czyli od „rozluźniającej gimnastyki umysłu" do skutecznych interwencji systemowych*, (w:) Józefik B., Górniak L., *Ewolucja myślenia systemowego w terapii rodzin. Od metafory cybernetycznej do Od metafory cybernetycznej do dialogu i narracji*, Kraków.

Hahladakis J. N., Iacovidou E. (2019). *An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling,* "Journal of Hazardous Materials"*,* Volume 380, https://doi.org/10.1016/j.jhazmat.2019.120887.

Hickel J., 2021, *Mniej znaczy lepiej. O tym, jak odejście od wzrostu gospodarczego ocali świat*, Kraków.

Iacovidou, E., Hahladakis, J.N. & Purnell, P. (2021). *A systems thinking approach to understanding the challenges of achieving the circular economy*, "Environ Sci Pollut Res" 28, 24785–24806, https://doi.org/10.1007/s11356-020-11725-9.

IPCC, (2023). *Summary for Policymakers*. In: *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1–34, doi: 10.59327/IPCC/AR6-9789291691647.001.

Juskowiak E., Mleczak J. (2023), *Jestem, więc myślę – wnioski z badań na temat myślenia matematycznego,* (w:) Juskowiak E (red.), *Współczesne problemy nauczania matematyki. Prace monograficzne z dydaktyki matematyki*, Poznań, https://press.amu.edu.pl/pub/media/productattach/j/u/juskowiak_red_wspolczesne_problemy_2023_amup.pdf#page=72 (21.04.2024).

Kronenberg J., Bergier T. (2010), *Wyzwania zrównoważonego rozwoju w Polsce*, Kraków.

Le Blanc, D (2015). *Towards Integration at Last? The Sustainable Development Goals as a Network of Targets*, "Sustainable Development", 23(3), 176–187. doi: 10.1002/sd.1582.

Meadows D. H. (2022), *Myślenie systemowe. Wprowadzenie*, Gliwice.

Mróz A., Ocetkiewicz I. (2019), *Co nauczyciele wiedzą o edukacji dla zrównoważonego rozwoju? Analiza wyników badań*, „Problemy Opiekuńczo-Wychowawcze", 582(7), s. 38–51, doi: 10.5604/01.3001.0013.5396.

Nilsson, M., Griggs, D. & Visbeck, M. (2016). *Policy: Map the interactions between Sustainable Development Goals*, "*Nature",* 534, 320–322. https://doi.org/10.1038/534320a.

Pradhan, P. i in. (2017), *A Systematic Study of Sustainable Development Goal (SDG) Interactions*, “Earth’s Future”, 5, 1169–1179, https://doi.org/10.1002/2017EF000632.

Pomianek T. (2023), S*kutki przemysłowej produkcji żywności dla klimatu i środowiska*, https://zielonyblog.wsiz.edu.pl/skutki-przemyslowej-produkcji-zywnosci-dla-kmatu-i-srodowiska/ (18.02.2024).

Pomianek T. (2024), *Chęć nadmiernych zysków powoduje utratę tego, co posiadamy*, https://zielonyblog.wsiz.edu.pl/chec-nadmiernych-zyskow-powoduje-utrate-tego-co-posiadamy-demokryt-z-abdery/ (29.04.2024).

Raworth K., (2021), *Ekonomia obwarzanka. Siedem sposobów myślenia o ekonomii XXI wieku*, Warszawa.

Richardson et al. (2023). *Earth beyond six of nine planetary boundaries*, “Science Advances”, 13 Sep 2023, Vol 9, Issue 37, DOI: 10.1126/sciadv.adh2458.

Rokita J. (2011), *Myślenie systemowe w zarządzaniu organizacjami*, Katowice.

Sachs J. D., Lafortune G., Fuller G., Drumm E. (2023). *Sustainable Development Report 2023. Implementing the SDG Stimulus. Includes the SDG Index and Dashboards*, https://s3.amazonaws.com/sustainabledevelopment.report/2023/sustainable-development-report-2023.pdf (21.04.2024).

Sieradzka M. (2023), *Zmiany klimatyczne. Raport ONZ opisuje cierpienia dzieci*, https://www.dw.com/pl/zmiany-klimatyczne-raport-onz-opisuje-cierpienia-dzieci/a-67015786 (23.11.2023).

Stefaniuk, M. (2021). *Environmental Awareness in Polish Society with Respect to Natural Resources and Their Protection (Overview of Survey Research),* „Studia Iuridica Lublinensia”, *30*(2), 357-379, http://dx.doi.org/10.17951/sil.2021.30.2.357-379.

Warburton, K. (2003). *Deep learning and education for sustainability*, “International Journal of Sustainability in Higher Education”, Vol. 4 No. 1, pp. 44-56. https://doi.org/10.1108/14676370310455332.

Weber, J.M., Lindenmeyer, C.P., Liò, P. and Lapkin, A.A. (2021). *Teaching sustainability as complex systems approach: a sustainable development goals workshop*, “International Journal of Sustainability in Higher Education”, Vol. 22 No. 8, pp. 25-41. https://doi.org/10.1108/IJSHE-06-2020-0209.

Webpages:

(www1) Krajowa Platforma Raportująca – SDG, https://sdg.gov.pl/ (20.04.2024).

(www2) Sustainable Development Report, https://dashboards.sdgindex.org/map (21.04.2024).

(www3) https://stockholmuniversity.app.box.com/s/kptviuiltbejoryhclmluojj3x9iivok (19.04.2024).

(www4) United Nations, *The 17 Goals*, https://sdgs.un.org/goals (access: 25.02.2024), https://www.rdocumentation.org/packages/stats/versions/3.6.2/topics/hclust (access: 23.02.2024).

(www5) https://www.un.org.pl/download (28.04.2024).