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MANAGEMENT OF SUSTAINABLE AND SECURE REGIONAL DEVELOPMENT

DOCTORAL DISSERTATION

SOCIAL SCIENCES
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Abstract

The concept of secure regional development (RD) is an alternative to secure sustainable development (SD), which places sustainability at the centre of interest. Minimising the impact of regional threats (RT) is essential for ensuring sustainable and secure regional development. The literature analysis of contemporary regional threats (RT) shows that ecological threats (ET) harm regions' sustainability.

The security of sustainability against ecological threats requires securing the associated sustainable development goals (SDGs) related to the security facets of the planet security theme of SDGs, which are related to ecological threats. This concept guides a sustainable development model that considers these security facets since the existing security models do not consider contemporary global ecological threats related to SDGs' security facets.

The dissertation examines ecological threats in the context of sustainable development goals. It suggests a model of securing SDGs against ecological threats for securing regional development (RD). The proposed model would allow the construction of an ecological security tool, providing the possibility of managing the security of regional development facets.

The security indicators related to securing from these threats were selected from the World Bank's SDGs database following the created ecological security model. Secondary data on the indicators for the G20 group countries were collected from the World Bank from 2010 to 2019.

The research addresses the following tasks: constructing an ecological security tool to measure secure, sustainable development levels in selected countries. The tool is created by developing a set of security indicators and clustering them using the k-means method; then finding the main cluster by studying the relationship among the six clusters that control and impact them, weighing the main cluster indicators, and ranking their four sustainability aspects by experts, then obtaining the best alternatives using (MCDA-TOPSIS) method to get the weight of each security indicator along with ranking G20 countries according to the four sustainability aspects, and analysing the obtained results.

This ecological security tool evaluates and ranks the ecological security performance of the G20 countries and compares the results among the G20 countries. Furthermore, the outcome of the security tool for any G20 country should be analysed, and the weaknesses should be highlighted to enhance the ecological security performance whenever possible.

The dissertation is divided into three chapters, a conclusion and an introduction.

Reziumė

Saugios regioninės plėtros (RP) sąvoka – tai saugaus darnaus vystymosi (DV) arba, kitaip tariant, tvariosios plėtros, alternatyva, dėl kurios darnumas atsiduria dėmesio centre. Regioninių grėsmių (RG) poveikio mažinimas yra būtinas, siekiant užtikrinti darnią ir saugią regioninę plėtrą. Šiuolaikinių regioninių grėsmių (RG) literatūros analizė parodo, kad ekologinės grėsmės (EG) kenkia regionų darnumui.

Tvariosios plėtros saugumas nuo ekologinių grėsmių reikalauja susijusių darnaus vystymosi tikslų (DVT), siejamų su DVT planetos saugumo temos saugumo aspektų, kurie yra susiję su ekologinėmis grėsmėmis, užtikrinimu. Ši sąvoka padeda mums kurti darnaus vystymosi ekologinio saugumo modelį, kuris nagrinėja šiuos saugumo aspektus, nes taikant esamus saugumo modelius neatsižvelgiama į šiuolaikines pasaulines ekologines grėsmes, susijusias su darnaus vystymosi tikslų (DVT) saugumo aspektais.

Šioje disertacijoje nagrinėjamos ekologinės grėsmės (EG) darnaus vystymosi tikslų kontekste. Joje siūlomas tvarios ir saugios regioninės plėtros modelis, orientuotas į į darnaus vystymosi tikslų (DVT) apsaugą nuo ekologinių grėsmių, siekiant užtikrinti tinkamą regioninę plėtrą (RP). Siūlomas modelis leido sukurti įrankį, suteikiantį galimybę valdyti regioninės plėtros ekologinį saugumą.

Rodiklių sistema, naudojama minėtam įrankiui sukurti, suformuota atrenkant ekologinį saugumą charakterizuojančius rodiklius iš Pasaulio banko Darnaus vystymosi tikslų (DVT) duomenų bazės, remiantis sukurtu saugumo ekologiniu modeliu. Statistiniai duomenys, atspindintys G20 grupės šalių rodiklius, buvo surinkti iš minėtos Pasaulio banko duomenų bazės, laikotarpis nuo 2010 iki 2019 metų.

Tyrime keliamas uždavinys sukurti priemonę, skirtą saugaus ir darnaus vystymosi lygiui pasirinktose šalyse įvertinti. Priemonė sukurta sudarant saugumo rodiklių rinkinį ir juos sugrupuojant (klasterizuojant), pasitelkus K vidurkių metodą; tada nustatoma pagrindinė grupė (klasteris), tiriant šešių juos kontroliuojančių ir jiems įtaką darančių grupių (klasterių) ryšį, po to įvertinant pagrindinius grupių (klasterių) rodiklius ir ekspertams įvertinant jų keturis darnumo aspektus; po to gaunamos geriausios alternatyvos, pritaikant multikriterį spendimų priėmimo TOPSIS metodą, siekiant gauti kiekvieno saugumo rodiklio reikšmę kartu su G20 šalių reitingavimu pagal keturis darnumo aspektus. Tokiu būdu yra sukuriamas įrankis, kuris gali būti praktiškai pritaikomas tvariam ir ekologiškai saugiam šalių vystymui.

Taikant šią sukurtą priemonę gali būti įvertinami ir reitinguojami G20 šalių ekologinio saugumo rodikliai; gauti rezultatai gali būti lyginami tarp G20 šalių. Įrankis leidžia analizuoti bet kurios G20 šalies plėtros politikos rezultatus ir tokiu būdu išryškinti jų trūkumus. Įrankis leidžia valdyti tvarią ir saugią regionų plėtrą, orientuojant ją į kuo geresnius ekologinio saugumo rodiklius.

Disertacija yra suskirstyta į tris skyrius; disertacija pradedama įvadu ir baigiama išvadomis.

Notations

Abbreviations

EU – European Union (liet. *Europos Sąjunga (ES)*);

SD – sustainable development (liet. *Darnus vystymasis (DV)/tvari plėtra – disertacijoje sąvokos lietuvių kalba* vartojamos kaip sinonimai*)*);

RD – regional development (liet. *Regioninė plėtra (RP)*);

SDGs – sustainable development goals (liet. *Darnaus vystymosi tikslai (DVT)*);

HLPF – High-level Political Forum on Sustainable Development (liet. *Aukšto lygio politinis forumas darnaus vystymosi klausimais*);

OSCE – Organization of Security & Cooperation in Europe (liet. *Europos saugumo ir bendradarbiavimo organizacija*);

G20 – 20 political group countries (liet. *Didžiojo dvidešimtuko politinės grupės šalys*);

ET – ecological threats (liet. *Ekologinės grėsmės* (EG));

NSDS – national sustainable development strategies (liet. *Nacionalinės darnaus vystymosi strategijos*);

ECC – environment carrying capacity (liet. *Ekosistemos talpa*);

TOPSIS – technique for order of preference by similarity to ideal solution (liet. *Pirmenybės eilės tvarkos pagal panašumą į idealų sprendimą technika*);

MCDA – multi-criteria decision analysis (liet. *Daugiakriterių sprendimų analizė*);

GDP – gross domestic production (liet. *Bendrasis vidaus produktas*);

AMR – anti-microbial resistance (liet. *Atsparumas antimikrobinėms medžiagoms*);

Indic. – indicator (liet. *Rodiklis*);

UNEP – United Nations Environment Programme (liet. *Jungtinių Tautų aplinkos apsaugos programa*);

IUCN – International Union for Conservation of Nature (liet. *Pasaulinė gamtos apsaugos organizacija*);

UN – United Nations (liet. *Jungtinių Tautų Organizacija* (*JTO*));

STEM – science, technology, engineering, and mathematics (liet. *Mokslo, technologijų, inžinerijos ir matematikos ugdymo modelis*).

Contents

Introduction

Problem Formulation

In the context of new technologies, globalisation, and environmental insecurities such as climate change, the world is encountering contemporary regional threats that hinder regional sustainable development. It is necessary to decrease pollution to maintain a “green” environment so ecological threats would not endanger sustainable regional development.

Global sustainable development needs to shift from value-added creation to broader aims by integrating security principles and embracing all spectrums of contemporary threats to ensure the interconnectivity of security with the 17 SDGs.

The principles of sustainability should underpin both the SDGs and security. The argument is about having a model that considers the impact of the new regional insecurities on the SDGs’ perspective.

Relevance of the Dissertation

It is unanimously agreed that fostering sustainable development is the way to achieve a prosperous future for countries, regions, and the planet (Foroudi et al., 2024). According to regional development theory, the management of regional development requires a reliable measurement tool based on a model. Therefore, the dissertation aims to create such a tool that would facilitate managing not only the sustainable and ecologically secure development of regions. The number of research studies in the context of “Ecological security and sustainability for regional development” on the *Web of Science* is 459. The study found that 331 out of 459 research studies (around 72% of the total) were conducted in the last five years from 2020 to 2025, while in 2024, there were 81 types of research related to this topic, which indicates the importance of this topic in recent years.

Object of the Research

The research object is sustainable and ecologically secure regional development. The research problem is focused on resolving it.

Aim of the Dissertation

The dissertation aims to develop a novel ecological security model and a tool to assess the ecological security performance of G20 countries, which could be used for these countries’ development management.

Tasks of the Dissertation

The following tasks are formulated and need to be carried out to achieve the aim of the dissertation:

1. To theoretically justify the links between securing regional development and the security aspects of SDGs.
2. To highlight the regional insecurities that require further examination, such as ecological threats.
3. To build a model of sustainable and secure regional development based on the security aspects of the SDGs by considering contemporary ecological threats.
4. To propose arguments for selecting a system of indicators that will be utilised to secure regional development against ecological threats.
5. To construct a novel management tool stemming from the created security model that allows for measuring and ranking sustainable develop-

ment ecological security levels; the model would facilitate the management of regional development for G20 countries to be sustainable and more ecologically secure.

Research Methodology

The following approach and research methods were chosen to investigate the object. The selection of the SDGs security indicators and extracting their attributes data indicators for G20 countries from the SDGs database is available at the World Bank as a credible source. The research methodology combines quantitative and qualitative approaches to analyse sustainable development, using country and indicator clustering along with PCA (Principal Component Analysis) methods.

The methodological approach relies on grouping ecological security indicators (clustering by k-means method) for the obtained 43 security indicators, then analysing the cluster characteristics and, accordingly, their interrelationships to find the main cluster that structured a system of indicators consisting of 15 critical indicators impacting the whole ecological security for G20 countries, then weighting this system of indicators by experts according to sustainability aspects.

The results and hypotheses were analysed using the multi-criteria decision-making TOPSIS method, which selects the best alternative from a set of alternatives to measure each country's ecological security performance and rank the G20 ecological security performance. The calculations were made using the Python program, and the results were verified using concordance and $\chi 2$.
The following *research steps* were carried out, whereas the research methods were applied in steps 3 to 6, which utilised the tools to collect and interpret data.

1. Building the model based on integrating security principles into the SDGs.
2. Identifying security indicators using the built SD security model.
3. Collecting "secondary data" of SDG security indicators from the World Bank organisation.
4. Clustering security indicators using the k-means method.
5. Analysing and grouping each cluster's characteristics to get the main cluster.
6. Weighing the security indicators of the main cluster and rating the four sustainability facets of these indicators by seven experts.
7. Performing a ranking of the G20 group using the ecological security tool.
8. The principle of the coefficient of concordance was used to check the reliability of the results.
9. Analysing the obtained results according to the countries' performance.

10. Evaluating the obtained results of the created ecological security tool over the G20 members to find the weaknesses and propose possible solutions for mitigation according to each country's rules and regulations.
11. Approbation of results is achieved by providing an example of a country for the case analysis method (selected: Saudi Arabia from G20 countries).

Scientific Novelty of the Dissertation

The study's novelty lies in building a sustainable development model that considers ecological security issues by identifying the security facets of concerned SDGs related to these ecological threats to measure ecological performance.
The analysis of existing studies has revealed a deficiency in the provision of a tool for measuring regional ecological security. The research proposes a security tool that can manage countries' ecological security performance.

As a result, the study's novelty lies in the following:

- Considering ecological threats to maintaining security in building an ecological security model that ensures the sustainability and security of regions.
- Measuring countries' ecological performance according to the constructed management tool based on the built ecological security model enables managing regional development sustainably and securely, in contrast to other studies that consider only the sustainable way.

The originality is discovering regional threat categories, such as (impending, new, ongoing, and revived threats), which could be generated from another threat category; these threats are described in sub-chapter 1.7.

The dissertation contributed to management science by expanding Systems theory and Regional development theory, indicating that contemporary ecological threats have to be considered while foreseeing the functioning of systems, including regions.

Practical Value of the Research Findings

The findings of the dissertation have important implications for practice:

- The determined framework of securing sustainable development enables practitioners (politicians, policymakers, institutions, and government) to better understand the complexity of securing the regional development approach and its pillars to further focus on implementation and development.

- The developed system of ecological security indicators identifies areas that would help detect gaps in regional development, allows the government to make effective policy decisions regarding regional development, and stimulates the improvement of weak parts of the regional development framework.
- The assessment model would help develop new regulations issued by the government for sustainable development implementation.

Defended Statements

The following statements, based on the results of the present investigation, may serve as the official hypotheses to be defended:

1. The proposed model for sustainable and secure regional development, which takes into account the measured environmental threats, will be useful in the G20 development management process that will enhance the body of management science and could be applied to future management research.
2. The research indicates challenges and gaps in the implementation of security of SD in regional development, such as a lack of confidence in pollution management and unpreparedness for implementation.
3. The regional development model needs to be expanded to ensure security against the identified contemporary environmental threats, categorised as imminent, new, ongoing and revived threats, which could be generated from other threat categories, that formulates the system of security indicators to evaluate countries' performance in the ecological security model.
4. System and Regional development theories have to be extended by adding a statement that contemporary ecological threats have to be taken into account while foreseeing factors affecting systems, including regions‘ functioning.
5. The ecological security measurement tool, constructed based on the ecological security model, can be utilised to enhance the security of the region's development.

Approval of the Research Findings

This dissertation is supported by publishing four critical articles, each contributing to exploring the impact of ecological threats on sustainable development and regional development of the G20. These articles have been published in internationally recognised scientific journals: one in *Web of Science* (WoS) and others in peer-reviewed publications and conference proceedings, with the research findings presented at international conferences and scientific seminars in Lithuania and abroad.

Structure of the Dissertation

The dissertation includes an introduction, three chapters, and a general conclusion. The scope of the dissertation is 149 pages and contains extensive references and a list of the author's publications on the dissertation topic. It also contains 21 figures, charts, and 26 tables distributed throughout the body text. In total, 166 literature sources were used in writing the dissertation's literature review.

The First Chapter discusses how the severity of ecological threats, rather than other regional threats, impacts securing regional development based on the eight security SDGs extracted.

The Second Chapter is based on securing regional development discussed in the First Chapter, security indicators are formed by selecting eight security SDGs related to ecological threats, the appropriate framework, and the required criteria for selecting the indicators in building the model.

The Third Chapter discusses the construction of a novel management tool based on the Sustainable Development (SD) Security Model, which is discussed in the Second Chapter and measures ecological security in G20 countries.

The flowchart for the dissertation's structure (source: created by the author) is provided. Refer to Figure 0.1, available in Zenodo link https://zenodo.org/records/15570821, for better figure resolution.

1

Theoretical Insights of Sustainable and Secure Regional Development

The general concept of this chapter is to integrate sustainability and security of regional development. The study of sustainable development is paired with studying SDGs that ensure maintaining sustainability. Similarly, the study of the security for regional development is paired with studying the impact of the external PESTLE (political, economic, social, technological, legal, and environmental) factors.

According to the systems theory that considers environmental influences and the regional development theory, factors that affect the security of regional development are regional threats.

Combining the above approaches to have sustainable and secure regional development requires the integration of both studies, which led to studying the security of SDGs against regional threats.

The study started with the regional development and sustainable development pillars and their goals.

Studying SDGs themes helps to understand how to secure the SDGs that belong to a particular theme.

This chapter introduces definitions of insecurity types, expands security views, categorises threats based on-premises, and identifies the challenging traditional conception of security intersecting with each other, listing non-traditional threats such as cyber threats, geoengineering, STEM (science, technology, engineering, and mathematics), etc., categorising the regional threats in terms of types, state, and premises and quantitative critical analysis that examining the regional threats in their linkage with regional development, security, and SDGs, and complying with the systems theory as well as the regional development theory.

The investigation focused on the security theories and the recommendations from security organisations such as OSCE (Organization of Security and Cooperation in Europe), which focuses on securing SDGs related to Regional threats.

This chapter aims to determine the critical threats that harm the security of SDGs; moreover, it shows how OSCE promotes and supports SDG security, bringing ecological threats to the centre of attention.

It also focuses on discovering ecological threats, the critical threats affecting the security of G20 countries, which require securing sustainable development against them, and measuring their impact on both developed and developing countries using the traditional approach of measuring the Human Development Index (HDI) and Ecological Footprint for understanding their behaviours.

Security against ecological threats would lead to the building of an ecological security model and then the construction of a management tool for the G20 countries to enhance their ecological security performance.

The theoretical analysis aims to provide an overview of major contemporary threats that affect regional development in one way or another. The authors seek to trigger discussion, ultimately allowing for efficient ways to prevent those threats or mitigate their impact (Chehabeddine & Tvaronavičienė, 2019).

The Global SD should be aligned with the security of regional development to ensure the interconnectivity of security with the 17 SDGs based on the principle of sustainability.

On the topic of this Chapter, two publications were published (Chehabeddine & Tvaronavičienė, 2019; Chehabeddine & Tvaronavičienė, 2021).

1.1. Regional Development Analysis

Region development is commonly characterised as the holistic growth of a community (social, environmental, healthcare, technological, cultural, and recreational) in a specific region. The region’s development should be founded on the optimal growth elements, which include social, natural, and economic development, and aimed at specific life-level maintenance and quality improvement through the mentioned constituents.

Regional development theory encompasses a range of ideas and frameworks that seek to understand how regions grow, develop, and change over time. It addresses the economic, social, and environmental factors that influence regional disparities and aims to provide strategies for promoting balanced development.

Regional development is a multidimensional concept determined by many factors. The board's areas of interest are sustainability and resilience, socio-culture and socio-economy, stakeholder involvement, and objectives (A Strategy Framework for Regional Development, n.d.).

The effective integration of sustainable development pillars at the regional level requires implementing a set of focused and particular actions that are complementary and fit within an overarching sustainable development framework.

Munasinghe's approach (Mensah, 2019) states that sustainable development entails taking sustainable measures to understand better the links between the economy, society, and the environment and ensure an equitable distribution of resources and opportunities for all current and future generations.

The concept mentioned above was reformulated as a comprehensive system comprised of three concentric circles: the economy exists within society, and both the economy and society exist within the environment. The extent to which these constraints are respected is measured using sustainability metrics.

Technical advances and regional competition are the most important environmental factors shaping the region's functions. Several external factors may affect the development of regional strategies. Economic, eco-space, socio-institutional, and ethical sustainability are accomplished within the region via integration within the orderliness of sustainability.

1.1.1. Regional Sustainable Development Pillars and Goals

There are similarities and commonalities between regional development pillars and sustainable development pillars, in which maintaining sustainable development contributes to maintaining regional development. Furthermore, studying the security of sustainable development through SDGs is more specific and measurable than studying directly the security of regional development.

The elements or pillars of sustainable development are the environment, society, and economy, which interact to develop the required sustainable development. Attending to one of these at the expense of the others is bound to lead to unsustainable dynamics and outcomes.

Table 1.1 Variables of sustainable development pillars and their sources for regions (Mensah, 2019), listed in Zenodo link https://zenodo.org/records/15570821, file # 1, show the sustainability pillars for regions with their sources that are part of the sustainable development pillars.

In exploring the relative importance of sustainable competitiveness pillars, sustainable competitiveness refers to the ability of a country, region, or company to achieve economic growth and development while ensuring environmental protection and social equity. It combines the principles of competitiveness, such as innovation, productivity, and efficiency, with sustainability goals, ensuring that economic activities do not compromise the ability of future generations to meet their needs.

While related, sustainable competitiveness is not the same as sustainability. Sustainability broadly focuses on meeting present needs without compromising future generations' ability to meet theirs, encompassing environmental, social, and economic dimensions. Sustainable competitiveness specifically integrates these sustainability principles into the competitive strategies of entities, aiming for long-term economic success that is environmentally and socially responsible. It has been found that robust governance practices, which encompass transparency, accountability, and adherence to the rule of law, have the potential to cultivate a stable and favourable atmosphere for sustainable competitiveness (Hassan et al., 2020). Effective governance can entice investment, foster economic stability, and facilitate the execution of sustainable policies and initiatives (Omri & Ben Mabrouk, 2020).

1.2. Sustainable Development and Sustainability Analysis

The conservation of the ecosystem is a crucial principle of sustainable development (SD), which means that development activities must be carried out according to the Earth's capacity (Mensah, 2019). According to Guillén-Royo, sustainable development necessitates action in three areas, including development strategies that encourage economic growth, social equality, and the reduction of adverse environmental impacts (Guillén-Royo, 2018). It has been defined in various ways, and in practice, SD has three dimensions: economic, environmental, and social (Andersson et al., 2022). Figure 1.1 below shows the pillars of sustainable development (environment, society, and economics) and how these elements are interrelated to develop sustainable development and consequently link them to regional development sustainability.

The sustainable development approach within regional development emphasises the need for economic growth to be balanced with social equity and environmental sustainability. It advocates for development strategies that consider long-term impacts on communities and ecosystems.

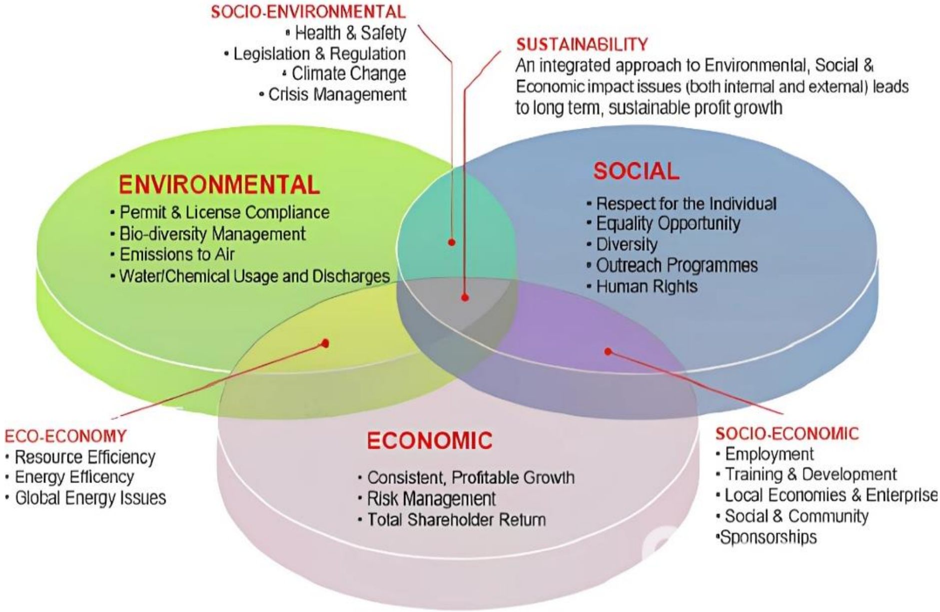

Fig. 1.1. Key elements of sustainable development (Jovovic et al., 2017)

Sustainable development synchronises economic, environmental, and social growth to increase overall intergenerational welfare while balancing intergenerational interest (Jin et al., 2022). It necessitates integrating environmental goals and preserving natural resources and human health, all of which help sustain present and future growth. The pillars of sustainable development are interdependent in the following ways: environmental–economic (economic costs of environmental protection), economic–environmental (pressure on environmental resources, environmental investment), environmental–social (human welfare, health care by maintaining a sanitary environment), social–environmental (ecological responsibility, consumption patterns), economic–social (providing jobs, good living, income), social–economic (labour quantity and quality) (Mangukiya & Sklarew, 2023).

Sustainable development has been the topic of extensive deliberation and has attracted much attention among environmentalists, economists, and policymakers. The term "sustainable development" (SD) is widely used in current political and environmental discourses.

Sustainability can be considered living within the constraints of environmental, technological, and social needs, while sustainable development is moving to the point where all human activity is sustainable. In 1987, the Brundtland Commission defined sustainable development as "Development that meets the demands of the present generation without jeopardising the potential to satisfy the needs of future generations" (*Urban Resilience and Development of New Orlean – PHDessay.Com (n.d.))*.

In achieving and maintaining sustainability, policymakers require timely information that shows whether a system is becoming more or less sustainable overall and detailed information on which features need to be improved the most.

1.2.1. Sustainable Development Goals

The United Nations promoted the 17 Sustainable Development Goals (SDGs) in 2015. Intersectional linkages among these objectives are especially revelatory of the forces structuring non-military security. Each goal has its own set of measurable indicators. The goals apply to all nations, with no distinctions between developed and developing countries. Though these goals are highly lofty, UN agencies and other organisations continue to promote these universal goals globally.

The SDGs superseded the eight Millennium Development Goals that unfolded from 2000 to 2015 (Case Studies | 2015 UN-Water Annual International Zaragoza Conference. Water and Sustainable Development: From Vision to Action. 15–17 January 2015, n.d.).

The United Nations created eight Millennium Development Goals (MDGs) from 2000 until 2015. However, in 2015, the United Nations (UN) proposed 17 new Sustainable Development Goals (SDGs), with targets for sustainability accompanying each pillar. It contained 17 global goals, 169 targets, and 230 indicators that all countries must meet by 2030 (*THE 17 GOALS | Sustainable Development*, n.d.).

Sustainable Development Goals (SDGs) are the guidelines for sustainable development. Following the establishment of the Sustainable Development Goals (SDGs) in 2015, It currently denotes a harmonious balance of environmental health, ecological vitality, and social order. It implies different inferences for different societies. SDGs are essential for all developed, transitory, developing, and developed countries. They interconnected international goals to attain zero hunger, quality education, gender equality, reduced inequalities, and sustainable communities by 2030, as shown in Figure 1.2 below.

Fig. 1.2. 17 Sustainable Development Goals (*THE 17 GOALS* | *Sustainable Development*, n.d.)

The SDGs are integrated (and indivisible) and create a balance between the three facets of sustainable development (economic, social, and environmental) for the whole world (developed and developing countries alike) to make them perform their best in reducing inequalities considerably (Kostoska & Kocarev, 2019). According to the SDGs, sustainable development aspires to achieve social progress, environmental balance, and economic growth. However, policymakers face the issue of implementing the SDGs concurrently due to multiple interlinkages within and between these goals, including synergy and potential trade-offs (Mangukiya et al., 2017) doing it equitably. However, these interconnections currently have a weak conceptual and scientific foundation to emphasise the urgent need for holistic and comprehensive techniques and tools to assess the nature and strengths of these interactions as well as how they affect policy and execution (Mangukiya et al., 2017).

1.3. Interrelation of Regional Development with Sustainable Development Goals

The development of regions is commonly understood as the holistic growth of a community (social, economic, environmental, healthcare, technological, cultural, and recreational) in a particular territory. As a result, the development of a region must be based on the optimal expansion of constituents of sustainable development pillars (social, environmental, and economic development) and aimed at specific life-level maintenance and quality improvement.

Sustainable development means a harmonious balance of environmental health, ecological vitality, and social order. This approach applies to all countries, regardless of their development level.

Table 1.2. 17 Sustainable Development Goals grouped into economic, environmental, and social pillars (created by the author)

Sustainable Pillars	**Associated Goals**					
Economic	SDG1 No Poverty	SDG2 Zero Hunger	SDG3 Good Health and Well-being	SDG 8 Decent Work and Economic Growth	SDG 9 Industry, Innovation, and Infrastructure	
Environmental	SDG 6 Clean Water and Sanitation	SDG 7 Affordable and Clean Energy	SDG 12 Responsible Consumption and Production	SDG 13 Climate Action	SDG 14 Life Below Water	SDG15 Life on Land
Social	SDG4 Quality Education	SDG5 Gender Equality	SDG10 Reduced Inequalities	SDG11 Sustainable Cities and Communities	SDG16 Peace, Justice, and Strong Institutions	SDG17 Partnerships for the Goals

The SDGs represent a well-balanced set of economic, social, and environmental goals and targets. To achieve the SDGs, countries must recognise and appreciate the existence of potential trade-offs and devise strategies to deal with them. The successful implementation of the SDGs will rely on unravelling the complex interactions between the goals and their targets. An integrated approach to sustainability would necessitate realising the potential of its vital dimensional pillars while also managing the tensions, trade-offs, and synergies among these dimensions. The SDGs are essential for promoting the long-term achievement of the three pillars of sustainable development (economic, environmental, and social)(*Transforming Our World: The 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs*, n.d.). These 17 SDGs, as shown above in Figure 1.2, are categorised into three sustainable pillars (social, environmental, and economic) and depicted in Table 1.2.

1.3.1. Sustainable Development Goal Themes

SDGs themes refer to the overarching topics and focus areas within the Sustainable Development Goals (SDGs) framework. These themes guide global efforts to address critical challenges. The 17 SDGs are analysed and found to be categorised into five themes, which are the 5Ps.

The SDGs' objectives and targets are interdependent but interrelated; for instance, addressing climate change issues (SDG 13) could benefit energy security (SDG 7), biodiversity (SDG 14), and oceans. Climate change (related to SDG 13) leads to extreme events, water-related disasters, and pressure on existing water resources (related to SDG 6) because the imbalance between evaporation and precipitation creates either a shortage or excess of water in the ecosystem. Accordingly, the shortage leads to water stress, whereas excess causes flooding. Climate change causes extreme weather occurrences, water-related calamities, and strain on existing water resources. Water is essential for the ecology of building resilient and sustainable settlements. The imbalance between evaporation and precipitation causes scarcity or an abundance of water in the environment. Water scarcity creates water stress, whereas surplus causes flooding.

The 2030 Agenda, which was endorsed by world leaders in September 2015 and included 17 Sustainable Development Goals (SDGs), entered into effect on 1 January 2016. The SDGs are organised around five primary pillars: people, planet, prosperity, peace, and partnerships, and they are evaluated regularly by the UN High-level Political Forum on Sustainable Development (HLPF). The 2019 HLPF met in July, themed "Empowering people and ensuring inclusiveness and equality", and conducted an in-depth evaluation of Goals 4, 8, 10, 13, 16, and 17.

The actions for achieving sustainability have positive connections with the SDGs related to environmental dimensions (Goals 6, 7, 12, 13, 14, and 15) as they mutually reinforce each other. However, these efforts may directly contradict the SDGs regarding social and economic factors (Goals 1, 2, 3, and 8). The SDGs incorporate the 5Ps spanning the 17 SDGs: people, planet, prosperity, peace, and partnership, emphasising the interdependence of the targets and the need for integrated and coordinated goal execution, as shown in Table 3 below.

Table 1.3. 5Ps concept in the 2030 Agenda for Sustainable Development (Created by the author based on Ho et al. (2019))

P's (Themes)	People					Prosperity					Planet					Peace	Partner-ship
SDG's	1	2	3	4	5	7	8	9	10	11	6	12	13	14	15	16	17
Inter-relation between P's	Interacted with each other															People & Pros-perity	People & Planet

Table 1.3 is important because it shows that each SDG belongs to a theme, which helps in the understanding of how to secure the SDGs that belong to certain themes. For instance, the themes of the security of the planet should mainly include the security of ecological threats. Therefore, Table 3 will be utilised in later sub-chapters.

The five themes of the SDGs are the 5Ps, and according to the study of the security of regional development, only two themes need to be focused on: those related to particular SDGs responsible for securing regional development and ecological threats, which will be explained in the next sub-chapters.

1.4. Investigating Links between Regional Development and Security

Regional development is linked to sustainability, and development is linked to security, both nationally and globally (Chehabeddine & Tvaronavičienė, 2020).

Regional development research is conducted to identify in-depth causes hindering development in particular regions and find ways to neutralise them to accelerate economic development. Consequently, the general level of living started to increase gradually.

As Khagram (2003) mentioned, “The brilliance of ‘sustainability’ lies in its ability to provide ‘space’ for severe attempts to deal with the real, dynamic, and complex relationships among societies, economies, and natural environments, as well as between past, present, and future. Within this broad space, a range of perspectives that differ on what is to be sustained, what is to be developed, the linkage between such differing views, and the extent of the future envisioned have emerged. What is to be sustained?”

The first connotation of regional development is economic. Differences in economic development can be measured using a wide range of indicators, e.g., GDP per capita, patterns of income distribution across society, structure of economic sectors, availability of resources, unemployment, gender equality, etc. Much attention is paid to those questions in the scientific literature (Monni et al., 2018).

The most common answer to this question is “life support systems”, where the life to be supported is, first and foremost, human life. What is to be developed?

As a rule, the economy is prioritised when development is discussed in the context of sustainability. Production growth is seen as providing opportunities for employment and consumption. What are the links between them?

To make the policies of regional development successful, It is required to be able to identify the reasons for regional disparities and social problems, which could be economic, social-economic, social-cultural, or environmental, because the indicators of regional performance that are based on GDP alone, consequently fail to consider broader questions about the distribution of resources in terms of social well-being, for example considering the question of “What kind of regional development and for whom?” or “What kind of development model is inclusive economically and socially?”

There is a nexus between security and sustainable development facets, both nationally and globally, according to Stewart (Stewart, n.d.). **Three types of connection could be distinguished:**

1. The immediate impact of security/insecurity on well-being and, consequently, development achievements, e.g., security’s role as part of set objectives.
2. The impact of insecurity on non-security aspects of development and economic growth, as well as the role of security in promoting these outcomes.
3. The way development affects security or the instrumental role of development.

– Security policies contribute to development policies to enhance security, and development policies contribute to security policies to enhance development.

There are connections between security and development through policies; however, security and development are indistinguishably linked in an increasingly interconnected and complex world, especially in the least-developed countries.

For over 20 years, security and growth have been linked through the idea of human security. The relationship may be complicated; lagging development can result in complaints and disputes that could jeopardise progress.

Conversely, high levels of security lead to development, further promoting security; unfortunately, this vicious cycle can be broken because it is simple to have high-security levels without necessarily seeing economic growth or to have both high security and development in the economy but not inclusive growth, perhaps leaving room for conflict.

To conclude, there is almost unanimous agreement about the width of the regional development scope. The security phenomenon is a wide array of contexts.

Systematising the distinguished aspects below, it can be stated:

First, environmental and ecological security is related to the depletion of scarce resources, leading to climate change. Much attention is given to this broad aspect of security, which emerges as food security, e.g., (Faridi et al., 2019; Tireuov et al., 2018), water security (Moumen et al., 2019), deforestation (Cherchyk et al., 2019), and energy security (Rogalev et al., 2018).

The second broad security aspect is human, community, and societal security. It focuses on widespread issues such as structural and cultural violence, notably gender violence, sexual and public health botheration, forced migrations, and economic and resource injustice.

The third security aspect is state-centred national defence, which focuses on traditional state rivalry, military war, the geostrategic Great Game, and new areas such as natural resources (water and oil) and dark operations in cyberspace.

The fourth security aspect is a hybrid mixed form of insecurity, which combines state military dimensions with forms of dislocation (food and water crises, trafficking, radical ideologies), disruptive groups (organised crime, gangs, terrorists, drug cartels, pirates, anti-democratic forces), and technologies affecting civil societies.

This sub-chapter aims to clarify the interrelation between regional development and security, whereas the next sub-chapters 1.6.1 and 1.7.1 explain how to select the security SDGs related to these threats. The first security (environmental and ecological security) is the main focus of this study since it covers regional issues, which will be discussed in the next sub-chapters.

1.5. Applicability of Management Theories for Securing Regional Development

Classical theorists like Taylor (1911), Fayol, and Weber (1922) contributed significantly to management practice developments that are still applicable today. These theories have persisted in some form or another all over the world.

- **Scientific management theories**

Taylor (1911) identified key elements in managing an organisation to reduce reliance on arbitrary methods and instead implement timed observations, leading to optimal practices.

- **Classical management theories**

They were heavily built upon by Fayol and Weber (1922). The Administrative and Bureaucracy Theory was developed simultaneously and designed to resolve the limitations of the scientific management theory. In contrast to Taylor's purely scientific study, Fayol's administrative theory proposed that every organisation had six major functions: management, business, finance, security, personnel, and labour. Today, organisations still practice the principles of Fayol because it encapsulate personal effort and team dynamics. However, the "unity of command" is less practised than in the past due to employees reporting to more than one supervisor.

– **Bureaucracy theory**

The theory was developed by German socialist Max Weber. He contended that all organisations are hierarchically organised, and all higher positions supervise and control the work being done by the lower positions (Weber, 1922). In Berturan's theory, organisations have a distinct hierarchical structure that helps maintain control. He encouraged the division of labour through the use of specialisation. In this way, employees only carry out their skills to the best of their ability. Decisions are based on merit, and the emphasis is on objectivity and depersonalised relationships between employees. The major drawback of the bureaucracy's application is its inability to meet today's highly technological environment demands. However, even though Weber's theory considers workers' humanity, it will result in an impersonal organisation without human interaction or subjectivity.

– **Neo-classical management and human behaviour theories**

Management scholars gradually began to move away from viewing employees as nothing more than an extension of machines and to consider human behaviour and employees' social needs.

By the early 1920s, Mayo (1933) disproved Taylor's suggestion that science guided maximum productivity and opposed the notion that people were nothing more than controllable extensions of machinery. As a result of a series of experiments known as the Hawthorne experiments (1927–1932), he determined that work performance was more dependent on working conditions and attitudes than economic factors. He said that paying more attention to the human side of work influences productivity. In contrast to classical philosophers who advocated for control and limiting human liberty, neo-classical economists focused on improving productivity and understanding human behaviour at work, such as motivation, conflict, expectations, and group dynamics.

Mayo's new concepts introduced more modern management theories, including systems, contingency, Theory X and Theory Y, and team-building theory. Integrating theories as they evolved to deal with varying conditions became increasingly necessary, and some of the most well-known human behaviour theories emerged.

The basic theory of Regional development theory has four stages

A. Location theory

From the point of view of modern regional development theory, the representative location theories mainly consist of Thunen's agricultural location theory and Weber's industrial location theory.

B. Central place theory

It extended the research on the inchoate regional development theory from the production field to the market field. This theory was established by Christaller and Lösch (1933). Deeply influenced by location theory, the central place theory is one of the theoretical bases of regional economics.

This theory proposed the concept of a "central place" and probed into the relationship between the central place and the hinterland. The central place theory is of great significance to studying the regional structure and still has particular theoretical references in regional planning today.

C. Scientific regional development theory

Regional economic development theory, with the core of regional economic growth, was widely developed and perfected after World War II. The representative theories mainly consist of balanced development theory and unbalanced development theory.

1. Balanced development theory

It originated in the 1940s. The representative theories mainly consist of "the theory of the big push", established by Rosenstein-Rodan (1943), and the "vicious circle of poverty", established by Nurkse (1953). The balance development theory believes that with the production elements of the interregional flow, the regional economy development level will tend to balance so that productive force and investment should be allocated to each region in equilibrium, and the balanced development of regional economics can be realised.

2. Unbalanced development theory

The opinion of unbalanced development theory is that the regional development gap will not shrink; on the contrary, it will expand. The representative theories mainly consist of the "growth pole" raised by Perroux, the "cumulative causation model" raised by Myrdal (1957), and the "Gradient elapse theory" raised by Vernon (1966).

3. Gradient elapse theory

It states that each country or region in the development of the gradient will transfer from a high gradient zone to a low gradient zone over time.

D. Innovation of regional development theory

Since the nineteen-eighties, with the intensive study on regional development, some new regional development theories have been formed. The two representative theories selected are associated with the central argument.

1. Industry cluster theory

This theory was created by Porter (1990), a famous American scholar, in the 1990s. The connotation of the industry cluster theory is that some interconnected companies, suppliers, related industries, and specialised institutions come together in a particular region and form effective market competition, regional agglomeration effect, scale effect, and external effect according to the regional cluster.

2. **Regional sustainable development theory**

The regional sustainable development theory emerged with the worsening of the global environment. The idea of sustainable development appeared in ancient times, but as a modern development theory, its direct theoretical source is the opinions of the Club of Rome. The German scholar Schmid (1995) pointed out in 1995 that it is most important for regional development planning based on the possibility and the necessity of sustainable development to formulate regional development goals according to the region's inherent characteristics and pay attention to the natural environment.

Compared with the conventional study of regional development, the regional sustainable development theory emphasises the coordination of the relationship among population, resources, environment, and development. This theory not only advocates the equilibrium among social goals, economic goals, and ecological objectives but also stresses the complexity and wholeness of the development process.

The connotation of cluster or Systems theory is that the system is interconnected with subsystems into an integrated system in a particular region and forms an effective regional agglomeration effect and external effect according to the regional cluster, contributing to managing regional development.

On the other hand, the regional development theory contributes to managing regional development since the necessity of sustainable development to formulate regional development goals according to the region's inherent characteristics to pay attention to the natural environment. The regional development theory emphasises the coordination of the relationship among population, resources, environment, and development (Bogdański, 2012). This theory not only advocates the equilibrium among social goals, economic goals, and ecological objectives but also lays stress on the complexity and wholeness of the development process.

The Systems theory and Regional development theory are the most suitable theories for managing regional development since these modern approaches consider various social, legal, political, technical, and economic factors in organisations, adopt technical systems, study the interrelated organisational systems with the environment, and consider environmental aspects.

They also present culture at the national rather than the individual level. These approaches focus on applying mathematical models and processes to management situations, considering macro and micro forces impacting the organisation to enhance productivity, as shown in Table 1.4 below in **bold font**.

Table 1.4. Summary of management theories (created by the author)

Management Theory	**Creator / Introduced by**	**Approach** **Focus Group**	**Definition**	**Limitation**	**Applicable to RD**	**Contributions to RD**	**Reference**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		Classical					
Scientific	Frederic Taylor, 1947	Individual work efficiency	It is mainly concerned with increasing the organisation's efficiency and workers' productivity based on management practices	Micro-Level	No	No	Bass & Barrat, 1976
Administrative	Fayol, 1949	Organisational efficiency		Macro-Level			
Bureaucracy	Weber, 1949	Bureaucratic Rationality		Lack of flexibility, especially concerning multitasking and teamwork			
		Neo-Classical (Behavioral)					
Hierarchy	Maslow	Determine the best way to manage people skills rather than technical skills in all organisations	Gaining a better understanding of human behaviour at work, such as motivation, conflict, expectations, and group dynamics, to achieve improved productivity	Micro - Level	Low	Only in Social aspects	Redding, 1994; Olum, 2004
Hawthorne	Mayo	Employee management affects their performance					
X & Y		Managers' thinking about their employees affects their motivation					

Continued Table 1.4

<table>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td rowspan="2">Contin-gency</td><td rowspan="2">Chandler, 1962</td><td>Modern Approa-ches (Quanti-tative)</td><td rowspan="6">These ap-proaches focus on applying mathemati-cal models and pro-cesses to manage-ment situa-tions, con-sidering the macro and micro forces im-pacting the organisa-tion to en-hance productiv-ity.</td><td rowspan="6">Macro-Level</td><td rowspan="6">High</td><td rowspan="6">Eco-nomic, Social, and En-viron-mental aspects</td><td rowspan="2">Hellriegel & Slocum, 1973</td></tr>
<tr><td>Consider-ing vari-ous social, legal, po-litical, technical, and eco-nomic fac-tors in or-ganisa-tions</td></tr>
<tr><td>Socio-technical</td><td>Bertalan-ffy, 1950</td><td>Adopting technical systems</td><td>Passmore, 1988</td></tr>
<tr><td>Situational</td><td>Codd, 1970</td><td>Studying the inter-related or-ganisa-tional systems with the environ-ment</td><td>Lorsch, 1967</td></tr>
<tr><td>Systems theory</td><td>Porter</td><td>Environ-mental aspects</td><td>Albrecht, 1983</td></tr>
<tr><td>Regional develop-ment</td><td>Schmid, 1995</td><td>It empha-sises the coordina-tion of the relation-ship among popula-tion, re-sources,</td><td>Hofstede, 1991</td></tr>
</table>

End of Table 1.4

1	2	3	4	5	6	7	8
		environment, and development. This theory not only advocates the equilibrium between social					

The dissertation discusses security issues in regional development, which are interrelated to sustainable development, consisting of interconnected subsystems and recognising each subsystem's internal dependencies.

The modern management theories describe the interrelations between the subsystems inside the system as shown below:

– Recognition of the internal interdependencies.
– Recognition of environmental influence.

As mentioned previously, regional development is related to sustainable development, while sustainable development consists of three interrelated subsystems (environmental, social, and economic). The external factors to the system (political, economic, social, technological, environmental, and regional law) are abbreviated as PESTEL for sustainable development and can be used for SWOT analysis. In this study, the external factors (PESTEL) related to regional development are ecological threats that stimulate environmental threats and create economic threats that affect the economy by lowering the real GDP.

The modern management approach utilises Systems theory, which consists of interconnected subsystems and confirms the circular theory; besides, it considers the environmental influences on our ecosystem. The theory has been used in this model for managing ecosystems to secure regional development by managing sustainable development and studying the external factor impact (ecological threats such as COVID-19) on our sustainable development subsystems (economic, social, and environmental).

Moreover, **the modern management approach applies the Contingency theory for managing risks** by measuring external factors by identifying and prioritising the ecological threats and studying their impact using the ecological carrying capacity approach, which utilises ecological footprint to mitigate them. Furthermore, digitalisation methodologies and SWOT techniques could be utilised to figure out the best technologies that could be used to secure our ecosystem, primarily to protect our global economic subsystem, such as IOT, big data, nanotechnologies, robotics, artificial intelligence, geoengineering, etc.

The Regional development theory, which belongs to the Systems theory under the modern management theories, was adopted as a concept for the dissertation.

Moreover, the contingency theory (Luthans & Stewart, 1977) was considered in securing the sustainable development of regions and managing the threats against them.

These theories consider the interrelated aspects of sustainable development, consisting of interconnected subsystems and recognising each subsystem's internal dependencies, such as social, legal, political, technical, and economic, with the environmental influence that presents culture at the national rather than individual level.

1.6. Security Theories

Some important notions in the security theories are required to be understood, such as security in sustainable development, ecological security, and security management:

- Security in sustainable development involves integrating security measures into sustainable development practices to ensure that development goals are resilient against threats such as climate change, resource scarcity, and geopolitical instability. It emphasises the need for peace and stability to achieve long-term sustainability.
- Ecological security focuses on protecting ecosystems and biodiversity to maintain the natural balance and resilience of the environment. It addresses threats like pollution, habitat destruction, and climate change, aiming to ensure that ecosystems can continue to provide essential services and support life.
- Security management involves the strategies and processes used to protect individuals, organisations, and communities from various threats. In the context of sustainable development, it includes managing environmental, social, and economic risks to ensure the safety and well-being of current and future generations.

1.6.1. Expanded Views of Security

New technologies are revolutionary and baffling enough to warrant new security paradigms that traditional international relations have ignored so far. Traditional boundaries break down as power concentrates on information technology and STEM.

The expanded view of security has opened the discussion of new technologies that introduce non-traditional threats that become vulnerable to regional security and, thereby, regional development (Searle, 2021). The classical view of security was described by Barry Buzan, who claimed that the concept of security is a more versatile, penetrating, and valuable way to approach the study of international relations than either power or peace (Buzan & Hansen, 2009).

However, security threats can have socio-economic roots, including races over natural resources, spillover effects of environmental degradation, economic and social disparities, economic and political migration, and natural disasters.

There are recent trans-state threats blurred by all sorts of flows and forces, from environmental dynamics to technological development, from human and animal migrations to microorganism infection, from terrorist groups to financial flows, and from climate change to the global mass culture due to globalisation that has both an integrative and fragmenting process, complex and asymmetrical interdependence, which increase the borderless of international relations, thereby shaping and transforming security issues in new and unexpected ways.

Security theorists interpret security in different ways:

- **Traditionalists** purport security against interstate military-political dangers for the sake of intellectual and pragmatic clarity.
- **Wideners** extend security concepts to interstate threats from social, economic, and environmental issues.
- **Deepeners** integrate all sources since insecurity comes from and affects all: states, individuals, private entities, communities, and the environment (Martinovský et al., 2019)

Security theories for new technologies

The realist perspective may underscore the actual dangers to traditional states as national boundaries erode. The traditional arms race has exploded into a technological race, with hacking, intrusion, and cyber warfare as the fifth domain of warfare.

The liberal internationalism perspective raises the importance of the technological tide that may emerge with a great deal of work and diligence on the part of many stakeholders. They would advocate international cooperation, regimes, and institutions to frame these new forces.

The constructivist perspective ascribes the new technological developments and that our cultural and psychological projections, anticipations, and fears can turn them against our interests.

Existing social and political structures are stretched, strained, and broken as power distribution shifts toward the complete interweaving of information as the new fabric of society. While legacy power structures remain coevolving alongside the exploding information economy, the distribution of force ownership of conventional assets has become increasingly diluted and disrupted.

The interrelated aspects of our technological world are as follows:
Cyberspace threats, artificial intelligence, technological development, and the vulnerabilities of global logistical networks are made possible by trade globalisation and information technology. However, malicious ideas emerge, allowing for novel forms of control via super-intelligent predictive algorithms, ubiquitous surveillance, and robotic/drone deployment. The "evolution of evolution (Breda et al., 2023);(Kelly, n.d.) may outstrip" the human ability to cope.

Generally, New dangers lurk at the intersection of human and technological co-evolution since the existing social and political structures are stretched, strained, and broken as power distribution shifts toward the complete interlinking of information as the new fabric of society.

The security perspective in the research is focused on regions/countries (macro level) such as the G20 countries.

Sustainable development is required to foster the prosperity of the regions, and the SDGs are created to achieve SD.

It is essential to integrate Deepner's security principles with SD, which integrates all sources since insecurity comes from and affects all states, individuals, private entities, communities, and the environment to achieve stable SD for regions.

The security of the SD of regions could be achieved through conserving sustainable development from regional threats.

The ecological threats are mainly new contemporary regional threats that harm regions affecting the whole world, especially G20 countries, such as climate change and geoengineering.

Geoengineering, while aimed at mitigating climate change, can potentially damage regions in several ways:

– Weather disruption. Techniques like solar radiation management could alter weather patterns, potentially causing droughts or floods in certain areas.
– Ecological impact. Ocean fertilisation, intended to increase carbon absorption, might disrupt marine ecosystems and harm biodiversity.
– Uneven effects. Geoengineering might benefit some regions while harming others, leading to geopolitical tensions.
– Acid rain. Injecting aerosols into the atmosphere could lead to acid rain, damaging crops, forests, and water bodies.
– Dependence and sudden stopping. Relying on geoengineering could reduce efforts to cut emissions. If stopped suddenly, it might lead to rapid climate change.

Therefore, there is a need to secure SDGs to have a secure, sustainable development and consequently secure and sustainable regional development.

The “security of regional development” concept refers to the idea that sustainable development in a particular region is closely linked to its security and stability. It encompasses a range of factors, including economic growth, social cohesion, political stability, the prevention of conflict, and, specifically, environmental sustainability.

The security of regional development is a complex and multifaceted issue that requires a holistic approach. By addressing economic, social, political, and environmental factors, stakeholders can work towards creating a secure and stable environment that fosters sustainable development. Collaboration among governments, civil society, and international organisations is essential to effectively tackle the challenges and promote a secure future for all regions.

In summary, security is a foundational element that influences the success of the Sustainable Development Goals. Without a stable and secure environment, efforts to achieve these goals may be severely hindered. Addressing security issues holistically can contribute to sustainable development and improve the quality of life for individuals and communities worldwide.

1.6.2. Organization for Security and Cooperation in Europe

Organization for Security and Cooperation in Europe (OSCE) is the world’s largest regional security organisation. It takes a holistic approach to security, considering political-military, economic, environmental, and human factors. As a result, it handles various security issues, such as counterterrorism, policing techniques, human rights, national minorities, economic and environmental activities, weapons control, and measures to foster confidence and security. All 57 participating States in North America, Europe, and Asia enjoy equal standing, and choices are made by the agreement that has political but not legal force.

The OSCE addresses challenges affecting our collective security, such as weapons control, terrorism, good governance, energy security, human trafficking, democratisation, media freedom, and national minorities.

The OSCE’s 13 SDGs for security are organised around five primary themes: people, planet, prosperity, peace, and partnerships. All five of these topics identify areas where the OSCE, as the world’s most prominent security organisation, makes an impact.

OSCE focused on some SDGs related to security, as shown in Figure 1.3, which shows that 13 out of 17 SDGs belong to security as reported by the OSCE organisation, and it guides the segregation of the critical SDGs related to secure regional development.

The OSCE has linked security and development since 1975 with the Helsinki Final Act. This comprehensive approach to security rests on the recognition that conflicts may arise from not only political and military threats but also social unrest, environmental damage, economic strains, and inadequacies in the legal system, the defence of fundamental liberties and human rights, all of which are important for achieving the Sustainable Development Goals.

The Security Day on “The OSCE and the Sustainable Development Goals” focused on two main objectives (OSCE Security Day Conference Focuses on Sustainable Development Goals – BDCD, n.d.):

- Analysing the relevance of the SDGs to the OSCE and vice versa.
- Analysing the role of the OSCE as a partner (in the spirit of Goal 17) can contribute to sustainable peace, security, and development.

Fig. 1.3. OSCE and the Sustainable Development Goals (OSCE Security Day Conference Focuses on Sustainable Development Goals – BDCD, n.d.)

OSCE utilises some sustainable development goals that are concerned with securing sustainable development. The first step in establishing a more suitable foundation for managing the interrelationships between security and sustainable development is to extend one’s perspective**.** The OSCE’s recognition of the security and environment relationship dates back much further than the Brundtland report to the 1975 Helsinki Final Act. Parallel to the global discussion, the OSCE has expanded its work in areas ranging from water management to disaster risk reduction, climate change, waste management, and energy security. The 2030 Agenda presents an opportunity for the OSCE to examine and strengthen its role in advancing the global sustainable development agenda.

1.7. Regional Threats

The existing studies mainly focus on studying sustainability models and their indicators. In contrast, this research focuses on identifying the impact of contemporary ecological threats on sustainable development to understand how to promote regional sustainable development.

Scientists analyse the listed threat (Beňuška & Nečas, 2021). Water unavailability in East Africa and possible solutions were discussed by Stelian and Juhasz (2022) and Mutandwa and Vyas-Doorgapersad (2023). The means of reducing food insecurity were scrutinised by Mizanbekova et al. (2018). Extremism and terrorism are elaborated in the works of Agbaje (2022), who focused on kidnapping crimes, and Bamigboye (2023) disclosed practices of commercial soldiers used for fighting terrorism in Africa. Somogyi and Nagy (Nagy et al., 2018) analysed climate threats to critical infrastructure and showed that heat waves caused by global warming harm critical infrastructure. Increasing dangers caused by a lack of cybersecurity were discussed by Kovács (2022), who pointed to the ransomware phenomenon. The insufficient involvement of women in STEM was analysed by Msosa et al. (2022). Environmental and ecological security related to the depletion of scarce resources, leading to climate change will be tackled first (Faridi & Sulphey, 2019; Tireuov et al., 2018; Moumen et al., 2018; Cherchyk et al., 2019; Rogalev et al., 2018).

1.7.1. Regional Threat Categorisation

The idea behind the regional threat categorisation is to find the critical threats that harm the security of regional development.

The following typology clarifies five broad types of situations or premises that constitute a security in which threats overlap and interact.

Five broad types of situations or premises constitute a security in which threats overlap and interact, and those new threats warrant new security paradigms that traditional international relations have ignored so far.

First, **traditional state-centred threats**. Examples include nuclear proliferation in India, Iran, and North Korea; espionage among leading nations; territorial challenges in Crimea, the Middle East, and the East China Sea; and regional tensions (Koreas, India–Pakistan, and Iran–Saudi Arabia).

Second, **new threats interact and combine with old threats**, **creating interlocking problems.** For instance, climate change (desertification of large swaths of the Syrian territory), misgovernance, economic hardship, overpopulation, factionalism, and the terrorist contagion from neighbouring Iraq (all “unconventional” threats) contributed to the Syrian civil war and foreign military intervention, which in turn heightened the (traditional) tension between Russia and the United States, between Iran and Saudi Arabia, and between Iran and Israel.

Third, **new developments of unconventional insecurity**, such as climate change and gender discrimination interplay, challenge established conceptual maps, definitions, and national policies. States and other security actors must innovate and combine forces unexpectedly. Non-physical security, diversification of threats, and the salience of identity are key effects of globalisation in the security realm. The new security environment in the twenty-first century is essentially intermestic (international and domestic). It combines more variables, dimensions, and instruments, including military or military-grade resources mobilised by non-state actors such as criminal gangs, irredentist movements, and terrorists.

Fourth, unconventional security challenges will likely shape our future. "Low politics" or "soft" issues have failed to register them as "systemic threats" and are often deprioritised in comparison to traditional, state-centred threats. They are now being increasingly recognised as "hard security" and "high politics" challenges in the twenty-first century. For instance, the massive migrations affecting Europe over the past few decades have fuelled nationalistic and anti-Islamic forces, the rise of authoritarian, anti-democratic, right-wing movements, electoral volatility, Brexit, and the possible unravelling of the European Union and the Western alliance.

Fifth, the future has already arrived in several ways. Some new threats appeared as traditional threats, such as diseases, gender violence, underdevelopment, and crime; these threats are profoundly modified today by globalisation, which warrants fresh examination. Recent trends explain what tomorrow holds: for instance, climate change is not some future threat; it has been affecting many regions for some time and will only worsen. Dominant countries, regions, social groups, genders, and races live in different geographical and social places and various time frames from the dominated. In particular, the powerful can externalise their negativities, such as pollution. The security implications of past, present, and future climate-related changes affect health/disease, migration, food availability, political instability, etc.

Regional security types and their associated threats are categorised into five types, as shown in Table 1.5.

Regional threats are categorised in terms of type, state, and premises

The new security vision identified challenging traditional security concepts intersecting with each other and introducing non-traditional threats such as cyber threats, geoengineering, STEM, etc. Hence, the new security vision expands these threats categorised into five types, three states, and five premises (Nardin, 2017).

Table 1.5. Regional threat types (created by the author)

Regional Threat Types				
State-centred national defence	**Human**	**Hybrid**	**Environmental**	**Ecological**
Military war, natural resources (water, energy, and oil), and dark operations in cyberspace	Societal security, food security, micro-enemies, global migration, populist, gender violence, forced migration	Combined military with dislocation (food and water crises), radical ideologies, disruptive groups (gangs, terrorists, anti-democratic groups), or technologies affecting civil societies (cybersecurity, STEM, supply chain, populist)	Threats coming from the living planet: ecosystem natural resources, CC, water security, energy security, and microorganisms and diseases	Threats that the social system imposes on ecosystems and other forms of life (CC, geoengineering, micro-enemies)

Forms of threats that do not have a state are trans-state (migrations, technological challenges, global crime, and terrorism), sub-state (gender issues, urban misgovernance), and non-human (ecosystem dynamics, micro-pathogens).

The following typology clarifies the five broad types of situations or premises that constitute a security in which threats overlap and interact.

Forms of threats that do not have a state are trans-state (migrations, technological challenges, global crime, and terrorism), sub-state (gender issues, urban misgovernance), and non-human (ecosystem dynamics, micro pathogens). Regional threats can be categorised into three states, as shown in Table 1.6 below.

Table 1.6. Regional threat states (created by the author)

Regional Threat States		
Trans-state	**Sub-state**	**Non-human**
Migrations, technological challenges, global crime, and terrorism	Gender issues, urban misgovernance	Ecosystem dynamics, micro-pathogens

Furthermore, Regional threats can be categorised into five premises, as shown below in Table 1.7.

Table 1.7. Regional threat premises (created by the author)

Regional Threats Premises				
Traditional state-centred	Old and new threats combined and interacted with traditional	New developments of unconventional threats interact to frustrate traditional conceptual	Upgraded old threats	Old threats affected by external factors (globalisation, pollution) warrant fresh examination
Nuclear proliferation, territorial challenges, and regional tensions	The civil war in the Middle East and the terrorist contagion, the (traditional) tension between giant and powerful countries	Due to the global erosion of borders among countries, the traditional distinction between external and internal security has become blurred, such as climate change, GD, criminal gangs, and terrorists	Massive migration, Brexit, anti-democratic rights, AIDS, Ebola, and COVID-19	Gender violence, food insecurity

Table 1.8. Quantitative analysis for regional threats by type (created by the author)

Regional Threat Categories	Regional Threats	A State-Centred National Defence	B Human	C Hybrid	D Environmental	E Ecological	Authors
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Human insecurity	Massive migration			✓			Campbell, 2019
	Gender-based violence		✓				Gerring, 2019
	Water availability				✓		Zawahri & Weinthal, 2019
	Food insecurity		✓	✓			Resende & Abdenur Erthal, 2019
Societal insecurity	Populist security		✓				Garrett, 2019
	Extremist & terrorism			✓			Joshi, n.d.
	Corruption			✓			Euromonitor Help – Euromonitor.Com, n.d.

End of Table 1.8

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
National insecurity	Critical infrastructure	✓					Addington & Manrod, 2019
Environment insecurity	Climate change				✓		Below, 2014
	Geoengineering					✓	Beevers, 2019
Global insecurity	Cyber security threats			✓			Gueldry, Luscombe & Richards, n.d.; Lifländer, 2019
	STEM			✓			Sebastiani, Sanchez & Manrod, 2019
	Energy insecurity	✓					Gueldry, Luscombe & Richards, n.d.
	Supply chain risks & uncertainty			✓			Gueldry, Luscombe & Richards, n.d.
	Oil Price shock	✓			✓		Euromonitor International; Formentos, & Gueldry et al., n.d.
	Global Trade war			✓	✓		
	Invisible foes, micro-enemies, pathogens, and global health insecurity (COVID-19)				✓	✓	
Quantitative analysis of regional threats		3	3	**8**	**5**	**2**	

*The details of the above tables are available in the Zenodo link https://zenodo.org/records/15570821 file # 1.

The new security vision identified challenging traditional security concepts intersecting with each other and introducing non-traditional threats such as cyber threats and geoengineering because the perception that geoengineering may cause more harm than good and that it could be deployed in ways that have profound security implications has opened up discussions about ways to govern geoengineering at the international level. In the long term, STEM introduced future challenges. Other pragmatic issues warrant more immediate consideration because of their repercussions. A unique dilemma arises where countless tasks can be automated and hit critical mass, causing catastrophic job loss and degradation of employment status. The socio-economic implications are profound during today's transition period and as this automation revolution materialises. Hence, the new security vision expands these threats and categorises them into five types, three states, and five premises.

The analysis of regional threats is obtained after gathering regional threat types, states, and premises to understand their interrelation with regional security. As shown in Table 1.8 above, it is found that high-impact threats on the ecosystem are hybrid types, trans-state, newly developed from unconventional threats, and the traditional ecological threats are the least researched, which warrant us to focus on ecological threats because they are the sources of other threats as shown in Table 1.8.

Conclusions on regional threats

The points below were concluded for the regional threats listed in Table 1.9 for each Regional threat.

- 1. Most of these threats are of a trans-state nature.
- 2. Most threats are new threats developed to frustrate traditional concepts.
- 3. Hybrid threats combine traditional with human or technological insecurity.
- 4. Ecological threats could cause environmental threats.
- 5. Old and new threat combinations, old threats affected by new external factors, and old upgraded threats have less focus, requiring more attention to predict further threats.

Table 1.9. Conclusions for new visions of each regional threat (created by the author)

Regional Threat Categories	**Regional Threats**	**Conclusion: New Visions**
Human insecurity	Massive migration	Exiting strong economic countries from the union.
	Gender-based violence	The consequence of GBV in many regions causes us to reconsider International relations and emphasise civil wars.
	Water availability	Mitigate many threats by mitigating one multiscalar threat.
	Food insecurity	Globalisation is needed to ensure a good quality food supply for sustainable human and food security.

Continued Table 1.9

Regional Threats Categories	**Regional Threats**	**Conclusion: New Visions**
Societal insecurity	Populist security	Implement the convenient approach to feel more secure against impending, new, ongoing, and revived threats.
	Extremist and terrorism	Contain some kind of terrorism by reducing enabling factors (state sponsors, weak states).
	Corruption	There is also a direct correlation between labour productivity (measured as GDP per person employed) and corruption levels.
National insecurity	Critical infrastructure	Most new trans-state threats depend on networking, enabling them to attack regions economically and socially. They also threaten ecological security, which deals with the disruptions and degradations that social systems impose on ecosystems.
Environment insecurity	Climate change	constructivism approach for minimising climate change threats by creating an agency to discuss both individuals and communities to underscore the significance of different applications of international relations.
	Geoengineering	Political methods have a strong impact on this threat mitigation.
Global insecurity	Cyber security threats	Predicting the threats from the interaction of new technologies impact on culture, politics, economics, values, etc.
	STEM	Risk management plan to mitigate interruption of productivity and satisfy employment rate.
	Energy insecurity	Political policies greatly impact the availability of vital sources that affect a country's economy, in addition to supply and demand.
	Supply chain risks and uncertainty	Adopting risk management strategy to terrorist threats.
	Oil price shock	Limited transportation due to social distancing, low demand for travelling lockdown shops and factories, and curfew hours.
	Global trade war	In combination with lower private sector sentiment and aggregate demand, the overall impact on inflation is slightly negative. Higher production costs and lower exports lead, in turn, to a decline in business investment.

End of Table 1.9

Regional Threats Categories	**Regional Threats**	**Conclusion: New Visions**
	Global trade war	Asian economies, Canada, Mexico, and the EU suffer significantly from declining exports to the US despite their currencies depreciating against the USD and some substitution into other markets.
	Invisible foes, micro-enemies, pathogens, and global health insecurity (COVID-19)	1 - Non-human threat of pathogens could be a trans-state threat. 2 - The root cause of the environmental source could be ecological. 3 - Other micro enemies can be upgraded.

*The details of the above table are available in the Zenodo link https://zenodo.org/records/15570821 file # 1.

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The revealed regional threats are interrelated with SDGs that belong mainly to the following threat categories:

- Climate, water, sanitation, and hygiene are new non-human environmental threats.
- Non-traditional threats, such as cyber threats, geoengineering, STEM, etc.
- Gender insecurities belong to old human sub-state threats affected by globalisation.
- Health threats (micro enemies belong to upgraded non-human ecological threats).

It is found that most of the regional threats are trans-state (Table 1.5), hybrid (Table 1.6), and newly developed conventional threats (e.g., climate, water security, geoengineering, and pathogens), and global threats (e.g., COVID-19) (Table 1.7).

Therefore, these contemporary regional threats (such as environmental threats such as climate change) are associated with the ecological threats which are part of the regional threats, especially these ecological threats affect the SDGs related to the planet security theme out of the five major themes of SDGs: people, planet, prosperity, peace, and partnerships, mentioned in Table 1.3.

1.7.2. Ecological Threats

Sustainable development changes its context in the conditions of accelerating global warming; a decade ago, economic growth was emphasised; now is the time to focus on the survival of the planet as a priority. Therefore, ecological security, in a rather broad sense (Wysokinska-Senkus, Senkus & Korombel, 2021), must be analysed, measured, and managed.

The ecological facets of sustainable development are strongly associated with the circular economy (Abdou et al., 2023). Alas, despite the immense importance of a green economy, regional development threats are less emphasised, or their research is rather sporadic, concentrating on separate phenomena instead of adopting a more systemised approach.

Sustainable development changes its context in the condition of accelerating global warming. Economic growth was emphasised a decade ago, and the planet's survival has become a priority. Therefore, understood in a rather broad sense, ecological security must be analysed, measured, and managed.

Ecological security means that hazards related to air contamination, soil, and water must be identified and grouped, and their importance level must be identified.

Emerging global risks such as biological invasions, climate change, land-use intensification, and water scarcity jeopardise sustainability; aside from the continual challenges posed by anthropogenic activities such as urbanisation, industry, aquaculture, and water flow changes, climate change and developing contaminants such as micro-plastics and anti-microbial resistance can create a global concern for sustainability. Furthermore, environmental degradation, mainly reflected in increasing levels of carbon dioxide (CO2) emissions, dominates the global discourse on climate change and its consequential global warming. Therefore, they primarily affect SDGs since they are unpredictable, difficult to control, and mobilised quickly through regions or the globe compared to other regional threats. Consequently, they are insecure about SD because it harms environmental development and, ultimately, SD.

Biological invasions, land-use intensification, and water scarcity jeopardise sustainability (Ho & Goethals, 2019). Furthermore, environmental degradation is mainly reflected in increasing carbon dioxide (CO2) levels. Emissions dominate the global discourse on climate change and its consequential global warming (Opoku et al., 2022).

It is necessary to understand how to avoid these ecological threats that threaten our regional development by measuring their harm as the main step in planning to protect our ecosystem against them. Previous research used conventional indicators to measure sustainability without considering the impact of ecological threats on our regional development. For example, the ecological footprint model measures sustainability by converting human resource consumption and bio-productivity in a country and compares the consumption footprint to the regional biocapacity, which is found to be insufficient to determine the country's sustainable development.

Recent scientific literature provides ample ecological threat analyses. The following interconnected domains can be distinguished: water security, food security, energy security, and health security.

The non-use of green energy sources emits toxic gases such as carbon dioxide and nitrogen monoxide, which are part of the pollution that impacts climate change and geoengineering and become an ecological threat to our ecosystem. Ecological threats are one of the threats that negatively affect sustainable development.

These threats harm our environment and prone regions to reduced disease resistance, the emergence of new infectious and non-communicable diseases (such as the COVID-19 pandemic), issues related to anti-microbial resistance (AMR), issues related to water security, food security, and consequently, human security where climate change is the root cause of these issues. Therefore, these threats to ecosystems, such as climate change, geoengineering, and micro-enemies, affect our economic sustainability, a pillar of sustainable development. Nowadays, ecological threats harm regional development due to their easy mobility through regions, harming economic development and sustainable development.

Therefore, understanding how to avoid these ecological threats is necessary.

It has been found that the ecological facets of sustainable development are strongly associated with the circular economy (Corona et al., 2019),

The circular economy relates to the study of ecological security in several ways:

- Resource efficiency. By minimising waste and maximising resource use, the circular economy helps preserve natural resources, contributing to ecological stability.
- Pollution reduction. Circular practices reduce pollution by promoting recycling and sustainable production, enhancing ecological health.
- Biodiversity conservation. Efficient resource use and waste reduction can lessen habitat destruction, supporting biodiversity.
- Resilience building. By creating closed-loop systems, the circular economy enhances the resilience of ecosystems against environmental shocks.

According to those mentioned above, ecological threats and their associated threats mainly harm our ecosystem since they are difficult to control and predict, especially at the macro level, which is measured in sub-chapter 1.8.3.

1.8. Measuring the Impact of Ecological Threats on Sustainable Development

In the context of “Ecological security and sustainability for regional development” on the Web of Science, 459 research papers were found in general, and 331 (around 72%) were produced in the last five years from 2020 to 2025. In 2024, 81 research efforts were related to this topic, which shows the importance of this topic in recent years.

Some examples of research include “Optimizing ecological security patterns considering zonal vegetation distribution for regional sustainability”(Xiang et al., 2023), “Regional Sustainable Strategy Based on the Coordination of Ecological Security and Economic Development in Yunnan Province, China” (Meng et al., 2023), and“Regional Ecology supporting Sustainable Development” (Mao & Deng, 2022). OSCE linked security to some SDGs (Security Days: The OSCE and the Sustainable Development Goals | OSCE, n.d.).

1.8.1. Developed and Developing Countries

First, define and calculate two important indices: the Ecological Footprint (EF) and the Human Development Index (HDI). The EF and HDI indicators are conventional indicators used by researchers to measure sustainable development, but they have been found to be insufficient in measuring the security of regional development. One of the most important contributions to developing a sustainability indicator was given by Rees (1992) with the development of an index called the “Ecological Footprint” or EF. The original methodology constructed a matrix “consumption/use of land”. The objective of this index is to calculate the necessary land area. This index aims to determine how much land is required to produce and maintain products and services used by a particular society to produce and support goods and services consumed by a determined community (Abdar et al., 2017).

The Ecological Footprint measures the quantity of “biologically productive” land or water needed for a population to be self-sufficient. This measurement considers the resources a population needs to (1) produce goods and (2) “assimilate” or clean up its waste. Biologically productive land and water can include arable land, pastures, and sea parts containing marine organisms. Worldwide hectares (gha), a measure of the quantity of biologically productive land with productivity comparable to the worldwide average, are used to describe ecological footprints. (*What Is Ecological Footprint? Definition and How to Calculate It*, n.d.).

Numerous factors are considered, and the Ecological Footprint computations might get intricate. Using the formula to determine a country’s ecological footprint by Tiezzi *et al.*:

$EF = \Sigma Ti/Yw \times EQFi$,

Ti is the annual amount of tons of each product *i* consumed in the nation, *Y*w is the yearly world-average yield for producing each product *i*, and *EQF*i is the equivalence factor for each product *i*.

This equation compares the amount of goods consumed in a nation relative to the average number of goods produced worldwide. Equivalency factors are used to convert a given land area into the appropriate number of global hectares. These variables vary based on the land use and year. When calculating an ecological footprint that considers a wide variety of products, yield factors consider how different types of land may have a small or more significant impact (What Is Ecological Footprint? Definition and How to Calculate It, n.d.).

Human Development Index (HDI)

It is a summary of average performance in three important areas of human development: knowledge, a long and healthy life, and a good level of living. The HDI is the geometric average of the three dimensions' normalised indices (Nations, n.d.).

The Human Development Index (HDI) is calculated as a combined metric for ranking nations based on their level of human development. It was introduced by the United Nations Development Programme (UNDP) in its first Human Development Report in 1990. The HDI aims to provide a broader picture of a country's development level beyond economic indicators like GDP per capita. It focuses on three basic dimensions of human development (Human Development Index (HDI) & Its Formula – UPSC OWL, n.d.).

– 1. Life expectancy at birth

This component measures the average expected lifespan of a population, reflecting the country's health status and longevity. It indicates people's ability to live long and healthy lives.

– 2. Education

This dimension is assessed through two indicators: mean years of schooling for adults aged 25 years and older, which reflects the average number of years of education received by people in this age group, showing the level of education among the adult population, and expected years of schooling for children of school-entry age, which calculates the total number of years of education a child who is ready to start school will receive, provided current trends in age-specific enrolment rates continue throughout the child's life. It indicates a commitment to education.

– 3. Gross national income (GNI) per capita

Adjusted to purchasing power parity (PPP), this element represents the average income of a nation's populace, indicating the standard of living. It is adjusted for the cost of living and inflation rates to compare countries fairly.

Calculation of HDI

The HDI is calculated by geometrically averaging the normalised indices for each of the three dimensions. The normalisation ensures that each indicator falls between 0 and 1, allowing them to be averaged. The formula for calculating the HDI value is:

$HDI = \sqrt[3]{(IHealth) \times (IEducation) \times (IIncome)}$, where IHealth is the index for life expectancy, IEducation is the average of the indices for mean years of schooling and expected years of schooling, and *IIncome* is the index for GNI per capita.

1.8.2. Measuring Countries' Sustainable Development

The conventional concept of classifying sustainable developed and developing countries used the following prerequisites for becoming sustainable development countries:

– Human Development Index (HDI) value

It measures how well humans live. The Human Development Index (HDI) is used to track a nation's accomplishments in longevity, access to education, and revenue. An HDI higher than 0.7 is considered to be "high human development", as the Human Development Data Center reported.

A country with 1.00 >HDI>0.90 is considered a highly developed country.

A country with 0.90>HDI>0.80 is considered a middle-developed country.

A country with 0.80>HDI>0.70 is considered a low-developed country.

A country with an HDI >0.7 is considered a developing country.

In addition to considering the country's development level, it achieves the conditions below:

– GDP (PPP> USD 22,000)
– IMF status is a good status
– To have an OECD membership
– World Bank status is acceptable

Accordingly, the following is found:

The highly developed countries of the G20 are Australia, Canada, France, Germany, Italy, Japan, South Korea, the United Kingdom, and the USA.

The medium-developed countries in the G20 are Saudi Arabia and Turkey.

The low-developed countries of the G20 are Argentina, Mexico, and Russia.

The developing countries of the G20 are Brazil, China, India, Indonesia, and South Africa.

Table 1.10. Grouping of the G20 countries based on the development level (created by the author)

SN	G20 Country	Country Development Status
1	China	Developing
2	India	
3	Indonesia	
4	Brazil	
5	South Africa	
6	Russia	Low developed
7	Argentina	Low developed
8	Mexico	
9	Saudi Arabia	Middle developed
10	Turkey	
11	Japan	High developed
12	South Korea	
13	Australia	
14	Canada	
15	USA	
16	France	
17	Germany	
18	Italy	
19	United Kingdom	
20	European Union	

– Global Footprint Network

It was reported that an Ecological Footprint greater than 1.7 is a condition for being among the developed countries (Ecological Footprint – Global Footprint Network, n.d.).

This measure estimates whether humans live within the means of nature. Considering an Ecological Footprint of less than 1.7 global hectares per person makes the resource demand globally replicable.

Note: Ecological Footprint can be measured in global hectares per person or in “number of Earths”, representing how many planets Earth would take if everybody had this footprint.

Therefore, the conditions to be a sustainable development country:

Human Development Index (HDI) > 0.7, Ecological Footprint> 1.7

Consequently, the upper right quadrant of Figure 4 below shows the sustainable development countries of the G20 group.

G20 countries were selected to measure sustainable development by measuring HDI and Ecological Footprint employed by footprint network organisation by using the link (Open Data Platform, n.d.) that shows each G20 country's position regarding HDI and Ecological Footprint along with their population represented by the circle size as shown in Figure 1.4.

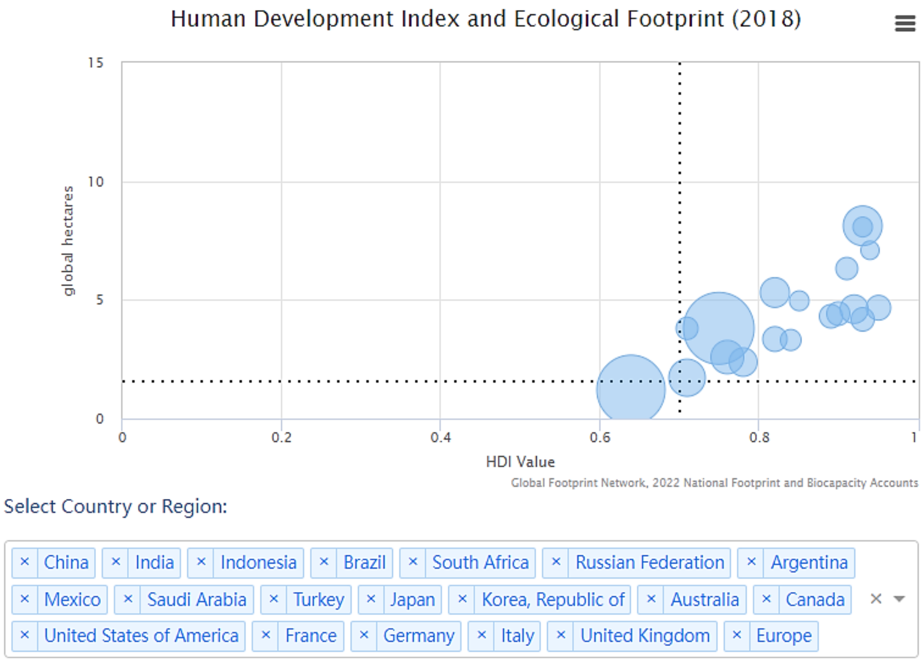


Fig. 1.4. Human Development Index and Ecological Footprint for G20 countries (Developing Countries 2024, n.d.; Open Data Platform, n.d.)

G20 countries can be grouped into four sustainable development SD clusters (developed, semi-developed, semi-developing, and developing). A country with scores greater than 0.80 in HDI is considered highly developed; in 2022, 80 of the 217 countries and territories tracked by the World Bank qualified as high-income, while 137 qualified as developing economies/countries (Developing Countries 2024, n.d.). It is important to remember that these two approaches are not always perfectly coordinated. For example, the UN would consider Argentina a developed country thanks to its 2019 HDI of .830, above the 0.80 threshold. However, the World Bank classifies Argentina as upper-middle income and is still growing based on its 2020 GNI of USD 9070, well below the USD 12,695 dividing line (Developing Countries 2024, n.d.).

1.8.3. Measuring the Impact of Ecological Threats on Sustainable Development

Ecological threats have been amply analysed in recent scientific literature. The following interconnected domains can be distinguished: water security (Cardoso et al., 2018), food security (Akhmadeev et al., 2018), energy security (El Iysaouy et al., 2019), and health security (Besenyő & Kármán, 2020). The non-use of green energy sources emits toxic gases such as carbon dioxide and nitrogen monoxide, which are part of the pollution that impacts climate change and geoengineering and becomes an ecological threat to our ecosystem.

Ecological threats are one of the threats that negatively affect sustainable development. These threats harm the environment and prone regions to reduced disease resistance, which causes the emergence of new infectious and non-communicable diseases (such as the COVID-19 pandemic), issues related to anti-microbial resistance (AMR), issues related to water security, food security, and consequently, human security where climate change is the root cause of these issues. Therefore, these threats imposed on ecosystems, such as climate change, geoengineering, and micro-enemies, affect our economic sustainability, a pillar of sustainable development.

The conventional concept of measuring the impact of threats on regional development is to compare the impact of the global risk scenario of ecological threats (dependent variable), such as COVID-19, on the economy (independent variable), such as real GDP, using the macro model for developed and developing countries.

The steps are as follows:

- Selecting the contemporary ecological threat (such as COVID-19).
- Selecting a group of developed and developing countries (such as the G20).
- Simulating the impact of the threat on these countries using, e.g., GDP retrieved from the Passport Database.
- Comparing the findings of both developed and developing countries (drop-in GDP using).
- Conclude what could be the convenient, sustainable development model to resist ecological threats.

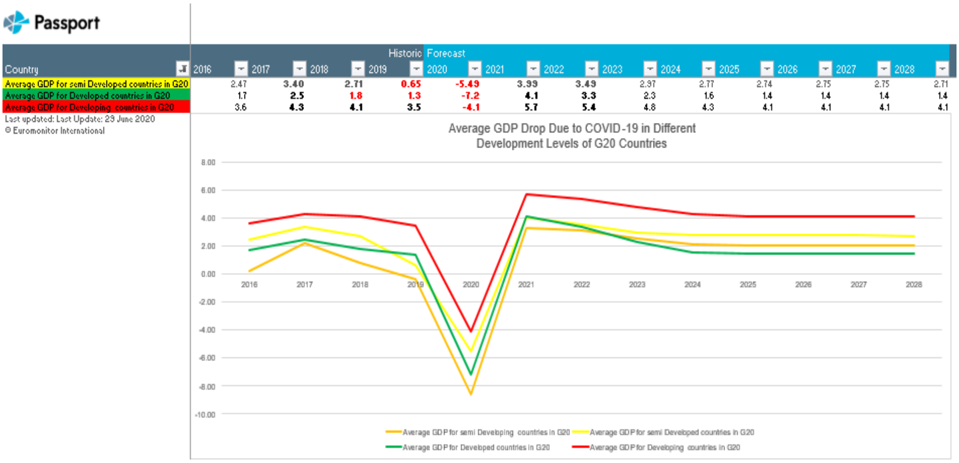
The ecological carrying capacity (ECC) is the maximum food supply with the capacity to sustain population growth. The population theory by Wu and Hu (2020) represents the connection between human economic and social practices and the natural environment centred on the link between a “carrier” or support object and a “bearing object” or pressure forces (Wu & Hu, 2020). The ecological carrying capacity (ECC) is composed of ecological resilience, represented by the environment carrying capacity, while ecological pressures/stress, represented by ecological threats (external factors) such as pollution, climate change, geoengineering, and new infectious and non-communicable diseases such as the COVID-19 pandemic (Wu et al., 2018).

The ecological carrying capacity (ECC) concept needs to be applied; COVID-19 is a valid sample of ecological pressure on regions that harm one of the ecological resources, "GDP" for the G20 countries.

The G20 political group was chosen because it represents around 80 per cent of the world's GDP, one-third of the global population, and 75% of all international trade. The scope was to study the impact of COVID-19, as an ecological threat, on the GDP as an indicator of economic development from 2017 to 2027. The secondary data was collected from the Passport Database to study the macro model's key indicators of developed and developing countries of the G20 group provided by Euromonitor International Company and powered by Clarivate Analytics. The data analysis will use a comparative analysis (qualitative method) to measure the economy's development under global risk scenarios.

Because of increased consumption, developed countries have high economic growth (GDP per capita) and ecological footprints. In contrast, developing countries have low economic growth (GDP per capita) and a low ecological footprint compared to developed countries. In developed countries, the increase of economic growth reaches a certain point, such that the country becomes a green energy consumer using renewable energy, where the ecological footprint will decrease, enhancing environmental and economic sustainability (Prause et al., 2019; Aye et al., 2017).

Figure 1.5 graphically presents the findings of COVID-19's impact on the G20's different development country categories. An interpretation of the obtained results is provided below.



Country	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Average GDP for semi Developed countries in G20	2.47	3.40	2.71	0.65	-5.49	3.99	3.49	2.97	2.77	2.74	2.75	2.75	2.71
Average GDP for Developed countries in G20	1.7	2.5	1.8	1.3	-7.2	4.1	3.3	2.3	1.6	1.4	1.4	1.4	1.4
Average GDP for Developing countries in G20	3.6	4.3	4.1	3.5	-4.1	5.7	5.4	4.8	4.3	4.1	4.1	4.1	4.1

Fig. 1.5. COVID-19 impact on various development countries categories of G20 (Euromonitor International, and created by the author)

*The details of the Figure 1.5 are available in the Zenodo link https://zenodo.org/records/15570821 file # 1, Figure 1.5.

Ecological threats transit globally, e.g., the COVID-19 disease, which affects global economic sustainability. The most significant impact appears to be on the most productive countries (developed countries, high population, etc.), such as the G20 countries.

Figure 1.5 was obtained after the forecasted GDP values for developed and developing countries of the G20 under the impact of COVID-19 were retrieved from the Passport Database.

It shows the average GDP of developed countries (green curve) and developing countries (red curve) within the same group over ten years, from 2017 to 2027.

It has been found that the difference in GDP drop due to COVID-19 from 2019 to 2022 is higher in the developed countries compared to developing countries, where the developed countries are highlighted in green, and the developing countries are highlighted in red (Chehabeddine & Tvaronavičienė, 2021).

The Research's main limitation is that it considers one macro model indicator (GDP) to evaluate the impact of the ecological threat on sustainable development.

This limitation could be neutralised by considering other relevant variables, either available or created, depending on the further study's aims.

Focusing on highly sustainable developed countries, such as the G20 countries, is highly recommended since ecological threats impact these countries.

1.9. Conclusions of the First Chapter and Formulation of the Dissertation Tasks

This chapter explored gaps that hinder regional sustainable development, specifically, trans-state ecological threats endanger regional sustainable development and, in turn, harm regional development.

Global sustainable development needs to shift from value-added to core aspects by integrating security principles through embracing all spectrums of contemporary threats to ensure the interconnectivity of security with the 17 SDGs.

Shifting from value-added refers to moving the focus from merely enhancing economic outputs to addressing fundamental issues that underpin sustainable development. It involves prioritising core aspects such as security integration by incorporating security measures to address global threats like climate change, pandemics, and geopolitical tensions.

Based on the literature analysis, the following essential conclusions could be stated:

1. Regional development is linked to sustainability, which consists of three interrelated subsystems (environment, social, and economic).
2. Sustainable development facets are linked to national and global security.
3. To have successful regional development, policies need to consider the reasons behind regional disparities, and social problems need to be identified, which could be economic, socio-economic, socio-cultural, or environmental.
4. Sustainable development synchronises economic, environmental, and social growth to increase intergenerational welfare while balancing intragenerational interests, irrespective of the country's development level.
5. Sustainable development goals (SDGs) are the guidelines for sustainable development, and they represent a well-balanced set of economic, social, and environmental goals and targets.
6. The OSCE has linked security and development by utilising some sustainable development goals that are concerned with securing sustainable development and addressing the interrelation of security and SD.
7. The most harmful regional threats are trans-state, hybrid, and newly developed ones, such as climate change, water security, geoengineering, and pathogens, which ground these contemporary regional threats into Ecological Threats threatening the planet's security.
8. Ecological threats are generally not extensively researched. However, focusing on them and their associated threats is necessary because they are the sources of other threats.
9. The difference in GDP drop was found to be higher in developed countries than in developing countries. The main research limitation is considering one macro model indicator (GDP) to evaluate the impact of the ecological threat on sustainable development. Depending on further research aims, this limitation could be neutralised by studying the effect of ecological threats using different indicators, either available or created.
10. The Systems and Regional development theories are the most suitable theories for managing regional development since these modern management theories describe the interrelations between the subsystems inside the system, recognition of the internal interdependencies, and recognition of environmental influence.

Therefore, the dissertation addresses the following tasks, outlining specific steps and objectives to achieve the research goals:

- **Literature Review:** Conduct a comprehensive review of existing research on ecological security and sustainable development indicators and evaluate the relationships between sustainable development and the security of regions.

- **Identify Key Indicators:** Determine the critical ecological security indicators relevant to regional development to develop a theoretical framework that establishes conceptual foundations while integrating security principles into sustainable development.
- **Model Formulation:** Create an ecological security model to assist in constructing a measurement tool that allows for measuring and ranking sustainable development ecological security levels; to have countries be sustainable and more ecologically secure.
- **Develop Methodology:** Design a methodology for measuring and evaluating ecological security performance, potentially using MCDA methods like TOPSIS.
- **Data Collection:** Gather data from reliable sources, such as the World Bank Organization for the G20 countries, to apply the developed methodology.
- **Analysis and Evaluation:** Analyze the data to assess ecological security performance and identify gaps or areas for improvement.
- **Validation and Testing:** Validate the measurement tool through expert evaluations testing the results using concordance and $\chi 2$.
- **Recommendations:** Propose improvement plans tailored to each G20 country's policies and regulations.
- **Documentation and Reporting:** Compile the findings, analysis, and recommendations into a comprehensive dissertation document.

2

Building an Ecological Security Model

This chapter aims to build a sustainable development (SD) model that considers ecological security, which can be managed by measuring the security indicators of the concerned SDGs for securing regional development from ecological threats. There is a need to measure the ecological threats that hinder the region's sustainable development, mining the ecological security indicators related to the eight security Sustainable Development Goals (SDGs), which can be retrieved from the World Bank database along with their data.

This model can measure and rank countries' ecological security, enabling policymakers to make appropriate decisions and actions. Previous studies mainly focused on reviewing and comparing the indicators developed to measure sustainable development. However, they do not measure the harm of ecological threats to regional development. They do not consider securing SD related to these ecological threats based on securing the SD Goals. In contrast, this research considers these security issues that affect SD security, which concerns policymakers and stakeholders (Chehabeddine et al., 2022). The connections between the sub-chapters below started from understanding the formation of security indicators by selecting SDGs related to ecological threats, selecting suitable frameworks, and setting the criteria for selecting ecological indicators to build the model.

The security SD model shifts from value-added to core aspects by integrating security principles to minimise the negative ecological impact.
One publication was published on the topic of this chapter (Chehabeddine, Grabowska & Adekola, 2022).

2.1. Formation of Sustainable Development Security Indicators

Indicators are the only tools that can make a problem visible. Many other factors can influence a policy process, and they are increasingly recognised for policy-making and public communication in disseminating data on how nations are doing in terms of their technical advancement, economics, society, and environment.

Many indicators are either grouped in a framework of categories or aggregated into an index to make a problem visible (Pravitasari et al., 2018); however, there are criteria to identify and select the appropriate indicators for aggregation, such as credibility, relevance, and legitimacy (Gan et al., 2017).

The relationship between the indicators and the facts they reflect must be empirically tested using proper methodologies, considering the challenges in selecting indicators and determining their weights. Indicators are accepted to indicate the fundamental structures, processes, and functions of the region-economical, the region's ecological, and social areas about the challenges and aims outlined in the normative dimension (problem and target-oriented representativeness) (Pravitasari et al., 2018).

Considering that some of the national index values are not updated annually, the most recent reports for each index are considered. A few easily understandable indicators must be established to attain this purpose (Pravitasari et al., 2018).

2.1.1. Frameworks of Sustainable Development Indicator

The main issue is establishing a measuring framework and choosing appropriate SD indicators. Some frameworks employ an accounting method or economic theory on various types of capital, while others base frameworks on causality, such as driving force–pressure–state–impact–response (DPSIR). Not only should the indicator structure specify what to measure, but it should also specify how to measure it (Gebara et al., 2016).

The planned SDGs and their targets have established a policy framework in their current format. The SDGs framework and the indicators must be conceptually and methodologically well-designed and tested before adoption to develop highly relevant indicators (Gebara et al., 2016). Experts should focus on the "indicator–indicated fact" relationship to guarantee the relevant SDG indicators.

In terms of SDGs, the policy framework has provided policy relevance; the themes of SDGs represent the key global challenges, such as biodiversity, inequality, climate change, and health. The properly operationalised targets will meet the criteria for SMART (specific, measurable, ambitious, realistic, and time-bound) targets, e.g., SD indicators.

The conceptual frameworks assist in focusing on and clarifying what to measure and expect from measurement and what types of indicators to utilise. The diversity of fundamental values, indicator processes, and sustainable development theories has led to the development and application of several frameworks.

The main differences among frameworks are how they conceptualise the key dimensions of sustainable development, their interrelationships, categorise the concerns to be examined, and the principles that explain the selection and aggregation of indicators, as shown below:

– Driving force–state–response frameworks

Variations in the pressure state–response paradigm are a driving force, state, and reaction (DSR) framework. In the DSR framework, each sign is characterised as a driving force, a state, or a response (United Nations, 2007).

Driving force indicators describe processes or activities that positively or negatively impact sustainable development (for example, pollution or school enrolment). Indicators of driving force define processes or activities that positively or negatively impact sustainable development.

– Issue or theme-based frameworks

The most common framework is issue or theme-based, notably common in government-issued national indicator sets. In these frameworks, indicators are classified into numerous issues related to sustainable development. The issues or themes are typically determined based on policy relevance. Most countries have used thematic frameworks worldwide to generate national sustainable development indicators.

– Capital frameworks

It seeks to assess national wealth as a function of the accumulation and interaction of several types of capital, including financial capital and manufactured capital products, as well as natural, human, social, and institutional capital.

– Accounting frameworks

Indicator systems based on accounting frameworks draw all indicators from a single database, allowing for sectoral aggregation and consistent classifications and definitions.

– Proposed indicator framework

They are based on the well-known “pressure–state–response” environmental policy model, including indicators and variables. An exhaustive examination of the environmental literature, assessment of available data, rigorous analysis, and broad collaboration with policymakers, scientists, and indicator specialists were utilised to choose the concerns and variables included. It also assesses stressors on such systems, natural resource depletion, and pollution rates because the size of such stressors is a good predictor of the pressure on the systems beneath them.

In the bottom line, the scientific literature used systematic and comparative analysis to develop the theoretical PSR (pressure–state–response) framework that embraces most spectrums of contemporary global threats, specifically, trans-state ecological threats that endanger the security of regional development. In contrast, most existing PSR frameworks focused on studying the structure of social and environmental interrelations to measure ecological security (Li et al., 2024).

2.1.2. Criteria for Identifying Sustainable Development Indicators

The problem of selecting indicators can be highly subjective(Rochet & Rice, 2005); therefore, undertaking a defined indicator-selection process can also increase the probability of selecting the most appropriate indicator (Tulloch et al., 2011).

The identification and selection of indicators can be made by using specified protocols, which include the following: conceptual model, a variety of indicators spanning distributional, indices and multivariate analyses, with extreme caution until guidelines are defined, time series has enough data to improve the ability to determine directional change reliably, data from a variety of sources to back up evaluations; and step-by-step reporting of the assessment procedure (Rowland et al., 2018)

Several selection criteria apply to the indicators. They should be relevant, methodologically sound, measurable, easy to communicate and access, limited in number, and outcome-focused (Rowland et al., 2018).

The relationships between these indicators and the facts they reflect must be empirically tested using proper methodologies and a theory (e.g., using a set of indicators).

Quantitative approaches, such as cluster analysis, multivariate linear regressions, principal component analyses, and correlations (Rowland et al., 2018), can be used to identify complementary indicators.

Combining multiple ecological indicators

Most ecological studies used multiple indicators, capturing multiple pathways to an ecosystem's collapse. Most indicators are evaluated independently because a decline in characteristic ecosystem features can highly affect the collapse risk. However, because ecosystem features do not exist in isolation, it is important to consider how multiple indicators contribute to the overall risk (Rowland et al., 2018).

Indices can be useful for showing temporal changes or anomalies. Multivariate analyses can be useful in identifying changes in relationships among indicators that may be less obvious when indicators are assessed independently (Bland et al., 2017). To evaluate the risk of collapse, indicators utilised in RLE (red list ecosystems) assessments must have well-defined collapse thresholds (Rowland et al., 2018).

Setting meaningful collapse thresholds for indices that combine multiple indicators and multivariate analyses can be challenging because these may capture multiple pathways to collapse, making it difficult to interpret how change affects the risk status, particularly when indicators have differential sensitivity to threats. Signals of collapse and mechanisms of change may be muted through averaging effects or generate bias from measurement (Burgass et al., 2013).

Indicators that aggregate data should only be employed after undergoing extensive testing to validate the ecological and mathematical hypotheses inherent in their design and functioning, a meaningful collapse threshold can be justified, there is a clear relationship between change in the index value and proximity to collapse, and uncertainties are acknowledged (Burgass et al., 2017). Creating expert-based rules to define ecosystem states that combine multiple indicators may also provide a valuable approach for combining indicators.

Guidelines/Criteria for selecting indicators

Identifying relevant indicators and developing suitable methods for assessing multiple indicators should include the following:

- Ecological relevance.
- Ability to set justifiable collapse thresholds (Bland et al., 2017).
- Relative sensitivity to threats can be quantified by examining exposure-response relationships between indicators and threats (Queirós et al., 2016).
- Spatial and temporal quality of data.
- A diverse suite of indicators that represent different pathways of change, including a combination of indicators for geographic distribution and functionality.
- Development of clear guidelines and standards for using indices and multivariate analyses, particularly for identifying thresholds of collapse.

For combining multiple indicators

- Use long-term time series with multiple data points (e.g., across a temporal gradient) to distinguish directional change from natural fluctuations.

– Use remotely sensed data, model simulations, and expert judgments elicited in a structure to support assessments when field data are lacking; and explicit reporting of steps in the assessment process, including indicator selection processes, indicators used and excluded the temporal and spatial quality of time-series data, and methods and assumptions for interpolation and extrapolations.

2.1.3. Selection of Sustainable Development Variables (data)

A careful review for selecting sustainable development variables is required in science and literature, as well as thorough consultation with experts from the environmental sciences, government, businesses, research institutes, and academic institutions (Esty et al., n.d.).

In an ideal world, these indicators would include all relevant aspects of functioning environmental systems, be distinct in their cause-effect relationships, be aggregate, scale-neutral, easy to quantify, and reflect the range of situations among political jurisdictions, including disaggregated data for major countries (Esty et al., n.d.).

Indicators' data are classified into four categories based on data availability: fully available, potentially available, related data available, and unavailable (United Nations, 2007). In addition, relevance is the second dimension of data adaptation, and it is classified into four categories based on relevance: related indicator relevant, relevant but missing, and irrelevant, as shown in Figure 2.1 below.

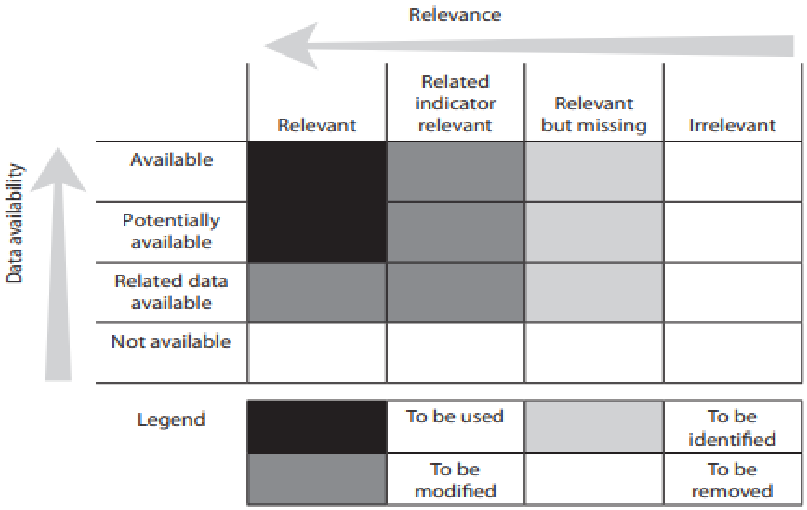


Fig. 2.1. Variable classifications of sustainable development indicators (United Nations, 2007)

Several countries have substantial data gaps, such as a lack of accurate data or a refusal to share information. The data are processed according to their weights; consequently, the index is calculated to be in the 100 per cent range, and all countries are graded from 100 per cent to zero per cent.

Variable grading

Evaluation of the data sets (variables) concerns the following criteria:

Relevancy – the degree to which the variable matches the issue of interest.

Accuracy:

– The reliability of the data source.
– Is the variable methodology well-established and widely adopted?
– The availability of other data for crosschecking to assess the accuracy of variables.

Coverage in space and time:

– The availability of the most recent data.
– The frequency with which the variables are updated.
– The spatial coverage of the variable.
– Whether the time series data can be constructed.

Certain variables are based on multiple data sources, in which case, each source is rated separately.

Each indicator contributes to one aspect of the index, and while calculating the score, to avoid unfair scoring and to decrease the impact of missing values, the constraint is followed, as the national score will not be computed if more than one value from each factor is absent (Faisal et al., 2020).

Sustainable development indicators must be created in order to provide a solid platform for decision-making at all levels and contribute to the self-regulation of integrated environmental and development systems (Kutay et al., n.d.). For this, it became necessary to define indicators that could measure and evaluate all the important aspects of the question.

2.2. Methodology for Building Ecological Security Model

For building the model, indicators must be selected in relation to the security of sustainable development of the region, considering the ecological threats, which will be explained in the following sub-chapter.

2.2.1. Selection of Security Sustainable Development Goals Related to Ecological Threats

The analysed aspect is the ecological threats to SDGs, which require an analysis of the SDGs' security indicators to build the ecological security model and construct the global ecological security tool accordingly.

After filtering the regional threats listed in Table 1.8 into two types (environmental and ecological threats), these threats can be segregated based on sustainable development goals, as shown in Table 2.1 below.

Table 2.1. Interrelation of Ecological Threats and SDGs (created by the authors based on Chehabeddine et al., 2022)

No	Ecological Threats	Threats Types & SDG			Descriptions from recent Web of Science sources
		Environ-mental	Ecological	Authors	
1	Water Avail ability	✓ SDG6		Zawahri & Wein-thal, 2014;Thakur et al., 2023	Spring water must be managed responsibly to maintain drinking water supplies and guarantee agricultural, ecological, and environmental integrity.
2	Critical Infra-structure		✓ SDG9	Addington & Manrod, 2019; Mohammad & Goswami, 2022	The unplanned and uncontrolled urbanisation of cities has put them under different ecological and environmental threats.
3	Climate change	✓ SDG13		Below, 2014; Birnintsaba et al., 2021	There is growing global concern about the unpredictable nature of climate change and rapid ecological degradation.
4	Geo-engineering		✓ SDG11	Beevers, 2019; Mohammad & Goswami, 2022	Geoengineering proposals diverge from understandings of global uncertainties and threats within scholarship on the globalisation of insecurity, instead identifying "the planetary" as a distinctive space of insecurity.
5	Energy insecurity	✓ SDG7		Sebastiani, Sanchez, and Manrod, 2019; Song & Tao, 2022	Significant increases in energy demand and higher pressure on energy supply pose a great threat to energy security.

End of Table 2.1

No	Ecological Threats	Threats Types & SDG			Descriptions from recent Web of Science sources
		Environ-mental	Ecological	Authors	
6	Invisible foes, micro-enemies, pathogens, and global health insecurity		✓SDG 13 ✓SDG 14 ✓SDG 15	Euromonitor International, (Gueldry et al., n.d.; Kaczmarek et al., 2024	Human well-being is affected by demographic, geographical, environmental, and economic changes in the modern world. Advanced and rapid technological advances have left countries without an adequate structural framework. The one health concept, rooted in the interconnectedness of human health, animal health, and the environment, addresses today's global health challenges. These include non-communicable and zoonotic diseases, anti-microbial resistance, ecosystem degradation, and food security.

*The details of the above table are available in the Zenodo link https://zenodo.org/records/15570821 file # 2.

According to Moyer and Bohl (2019), several SDGs are closely related to human development, indicating a tendency to develop programmes that consider human development and environmental elements together. The environmental hazards related to the environment of our living planet, for instance, climate change, water security, and energy security, while the ecological threats are related to ecosystems and other forms of life, such as geoengineering, micro-enemies, pathogens, and pollution. Both types of threats are interlinked.

These ecological threats, which are trans-state and non-human, reflect the SDG insecurities, such as water, energy, infrastructure, cities, footprint, biodiversity, and terrestrial ecosystems. It has been found that ecological security can be covered by the eight security SDGs mentioned in Table 2.1 above.

The reasons behind the selection of these eight security SDGs are discussed below.

This research focuses on the planet and prosperity SD security themes listed in Table 1.3 because ecological threats endanger them. The six environmental

SDGs that belong to planet and prosperity are (6, 7, 12, 13, 14, and 15). In addition, some ecological threats are closely related to human development, indicating a tendency to develop programs to consider human development and environmental elements together; therefore, other threats belong to the prosperity theme, such as SDG 9 critical infrastructure is related to ecological threats to be considered, as well as SDG 11 sustainable cities belong to social sustainability and related to ecological security recommended by OSCE for securing SDGs under the planet theme.

In conclusion, the eight SDGs (6, 7, 9, 11, 12, 13, 14, and 15) are related mainly to mitigating ecological threats.

2.2.2. Selection of Security Indicators

For mining security SDG indicators related to the mitigation of ecological threats, an international World Bank database is used (e.g., the World Bank database is used since it has an SDGs database). Filtering these SD goals into the required eight security goals allows for getting the related indicators.

The World Bank Group is a significant source of information on funding for developing countries worldwide. It provides various financial items and technical assistance and helps countries share and apply cutting-edge information and solutions to their problems (*Who We Are*, n.d.). They partner with governments, such as the International Bank for Reconstruction and Development (IBRD) and the International Development Association (IDA), which provide developing-country governments with finance, policy advice, and technical aid. IDA concentrates on the world's poorest countries, whereas IBRD aids middle-income and creditworthy poorer countries. Furthermore, the International Finance Corporation (IFC), the Multilateral Investment Guarantee Agency (MIGA), and the International Centre for Settlement of Investment Disputes (ICSID) are all focused on supporting the private sector in developing nations.

The World Bank Group supports private enterprises, including financial institutions, with finance, technical assistance, political risk insurance, and dispute resolution through these entities. The World Bank database is the official organisation providing United Nations sustainable development (UNSD) indicators; accessing the database is done by logging into the databank – World Bank website (The World Bank, n.d.).

The SDGs' objectives and targets are not interdependent but interrelated (Tosun et al., 2017). For instance, addressing climate change issues (SDG 13) could benefit energy security (SDG 7), biodiversity (SDG 14), and oceans (Le Blanc, 2015).

Climate change (related to SDG 13 and SDG 6) leads to water-related disasters because the imbalance between evaporation and precipitation creates either a shortage or an excess of water in the ecosystem (Yadav & Zeeshan, 2022).

The sequence of selecting indicators is as follows:

- Selecting the Sustainable Development Goals database from the available 84 databases is our concern for securing the SDGs.
- Then, select the targeted goals, and the eight security SDGs (6, 7, 9, 11, 12, 13, 14, and 15).
- Apply the filter in the series drop list, as discussed previously; these specific goals are related to ecological security.

The description of some of the eight security SDGs is as follows:

SD Goal 6 – ensure universal access to clean water and sanitation and sustainable water management.

SD Goal 7 – ensure accessible, affordable, reliable, sustainable, and modern energy for all.

The percentage of energy from renewable sources in gross final energy consumption is one measure of this priority.

SD Goal 9 – ensures the building of resilient infrastructure, promotes sustainable industrialisation and fosters innovation through efficient and healthy transportation by minimising CO2 emissions.

SD Goal 11 – make cities and human settlements more inclusive, safe, resilient, and sustainable by having safe and healthy cities through minimising losses related to city disasters and the environmental impact of cities, such as solid waste and pollution. Municipal environmental management is the environmental activities local authorities perform to enhance their city's security (Mostovoy et al., 2021).

SD Goal 12 – ensure sustainable consumption and production patterns. Consumption patterns have to be changed; stewardship of resources has to become a lifestyle; the circular economy has to become an integral part of daily life; organic farmers are a natural choice.

The indicator, e.g., the share of certified organic agricultural area in organic farms in the total agricultural area of agricultural holdings, has improved in the last decade.

SD Goal 13 – take immediate action to combat climate change and its consequences.

Economic growth leads to an increase in energy consumption, which, in turn, leads to the emission of CO2 into the atmosphere. Switching towards renewable energy sources is an inevitable choice for producers and households.

The priorities are effectively reducing CO2 concentration in the atmosphere and introducing innovative technologies to use available energy sources, including geothermal energy development.

SD Goal 14 – the need to protect the oceans and seas, e.g., “biodiversity protection”.

Tourism activities must be rethought to prevent urbanisation and deterioration. The priority is also to increase the share of the maritime economy sector in GDP and increase employment in the maritime economy. An indicator describes the percentage of fish stocks within sustainable levels (Sun & Ye, 2022)

Therefore, critical areas of biological diversity must be identified and protected. SD Goal 15 – the protection of the terrestrial ecosystem, sustainable forest management, and combating desertification.

Overusing agrochemicals has led to the destruction of natural resources and reduced production. Such a form of agriculture relies heavily on inputs, including seeds, pesticides, fertilisers, and irrigation water, leading to higher production costs and adversely affecting the health of humans and animals (Abdar et al., 2022). The indicator is the share of forest land in the land area, about 30%. This goal’s degree of implementation is determined by the indicator of the percentage of devastated and degraded land requiring reclamation in the total area.

2.2.3. Ecological Security Model Construction

Building a model has two main steps: the conceptualisation phase, in which the goals are set, and the operationalisation phase, which selects appropriate targets from existing sets or formulates new ones in which the indicators are formulated.

In this research, the conceptualisation phase is based on securing regional development, which depends on the security of sustainable development against ecological threats and is based on OSCE recommendations.

The operationalisation phase breaks down these goals’ objectives into tasks, which are then rolled down into security SD indicators for each task, as explained by the World Bank Development.

The retrieved indicators of the goals were exported to a spreadsheet file from the World Bank’s databank for further processing.

By filtering 1443 indicators available in the World Bank into 404 sustainable development indicators, then filtering them into 43 security indicators, considering only the eight security SDGs. The list of indicators and their implications is listed in Table 2.2 below.

Table 2.2 lists them in the same sequence from top to bottom, starting with environmental indicators and ending with economic indicators. Table 2.2 shows the targeted direction of change based on their long definitions, statistical concepts, methodology, and data availability for G20 countries.

Table 2.2. List of 43 indicator implications (created by the author, based on the World Bank – Sustainability database)

No	Indicator Description	Sustainability Pillar	SDGs	Targeted direction of change	Data Availability
1	People using at least basic drinking water services (% of the population).	Environmental	6	↑	Yes
2	People using safely managed drinking water services (% of the population).	Environmental	6	↑	Yes
3	People practising open defecation (% of the population).	Environmental	6	↓	Yes
4	People using at least basic sanitation services (% of the population).	Environmental	6	↑	Yes
5	People using safely managed sanitation services (% of the population).	Environmental	6	↑	Yes
6	People with basic handwashing facilities, including soap and water (% of the population).	Environmental	6	↑	Yes
7	Annual freshwater withdrawals, total (% of internal resources).	Environmental	6	↓	Yes
8	Level of water stress: freshwater withdrawal as a proportion of available freshwater.	Environmental	6	↓	Yes
9	Renewable internal freshwater resources per capita (cubic meters).	Environmental	6	↑	Yes
10	Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal).	Environmental	6	↑	Yes
11	Change in the extent of water-related ecosystems over time.	Environmental	6	↓	No
12	Access to electricity (% of the population).	Environmental	7	↑	Yes
13	Access to clean fuels and technologies for cooking (% of the population).	Environmental	7	↑	Yes
14	Renewable electricity output (% of total electricity output).	Environmental	7	↑	Yes
15	Renewable energy consumption (% of total final energy consumption).	Environmental	7	↑	Yes
16	The energy intensity level of primary energy (MJ/$2011 PPP GDP).	Environmental	7	↓	Yes
17	Air transport, passengers carried	Environmental	12	↓	Yes
18	Railways, passengers carried (million passenger-km).	Environmental	12	↓	Yes
19	CO2 emissions (kg per PPP $ of GDP).	Environmental	12	↓	Yes
20	Number of deaths, missing persons, and directly affected persons attributed to disasters per 100,000 population.	Environmental	12	↓	No

End of Table 2.2

No	Indicator Description	Sustainability Pillar	SDGs	Targeted direction of change	Data Availability
21	Direct economic loss in relation to global GDP, damage to critical infra-structure, and a number of disruptions to basic services attributed to disasters.	Environmental	12	↓	No
22	PM2.5 air pollution, mean annual expo-sure (micrograms per cubic meter).	Environmental	12	↓	Yes
23	Adjusted net savings, excluding particu-late emission damage (% of GNI).	Environmental	12	↑	Yes
24	Coal rents (% of GDP).	Environmental	12	↓	Yes
25	Forest rents (% of GDP).	Environmental	13	↓	Yes
26	Mineral rents (% of GDP).	Environmental	13	↓	Yes
27	Natural gas rents (% of GDP).	Environmental	14	↓	Yes
28	Oil rents (% of GDP).	Environmental	14	↓	Yes
29	Total natural resources rents (% of GDP).	Environmental	14	↑	Yes
30	A number of sustainable tourism strate-gies or policies and implemented action plans with agreed monitoring and evalu-ation tools.	Environmental	14	↑	No
31	Droughts, floods, extreme temperatures (% of the population, average 1990-2009).	Environmental	14	↓	Yes, but no available records
32	Disaster risk reduction progress score (1-5 scale; 5=best).	Environmental	15	↑	Yes, but no available records
33	The proportion of national exclusive economic zones managed using ecosys-tem-based approaches.	Environmental	15	↑	No
34	Aquaculture production (metric tons).	Environmental	15	↑	Yes
35	Capture fisheries Production (metric tons).	Environmental	15	↓	Yes
36	Total fisheries Production (metric tons).	Environmental	15	↓	Yes
37	Marine protected areas (% of territorial waters).	Environmental	15	↓	Yes
38	Forest area (% of land area).	Social	11	↑	Yes
39	Terrestrial and marine protected areas (% of the total territorial area).	Social	11	↑	Yes
40	Terrestrial protected areas (% of total land area).	Social	11	↑	Yes
41	Fish species threatened.	Economic	9	↓	Yes
42	Mammal species threatened.	Economic	9	↑	Yes
43	Plant species (higher) threatened.	Economic	9	↓	Yes

*****The list of indicators, with their data from 2010 to 2019, is provided in the Zenodo link https://zenodo.org/records/15570821 file # 2, for further details.
*The series of metadata is provided in the above Zenodo link for further details.

Building the flowchart for the model starts from regional development. It goes towards the security of sustainable development goals, as shown in Figure 2.2 below, which describes the proposed SD ecological security model.

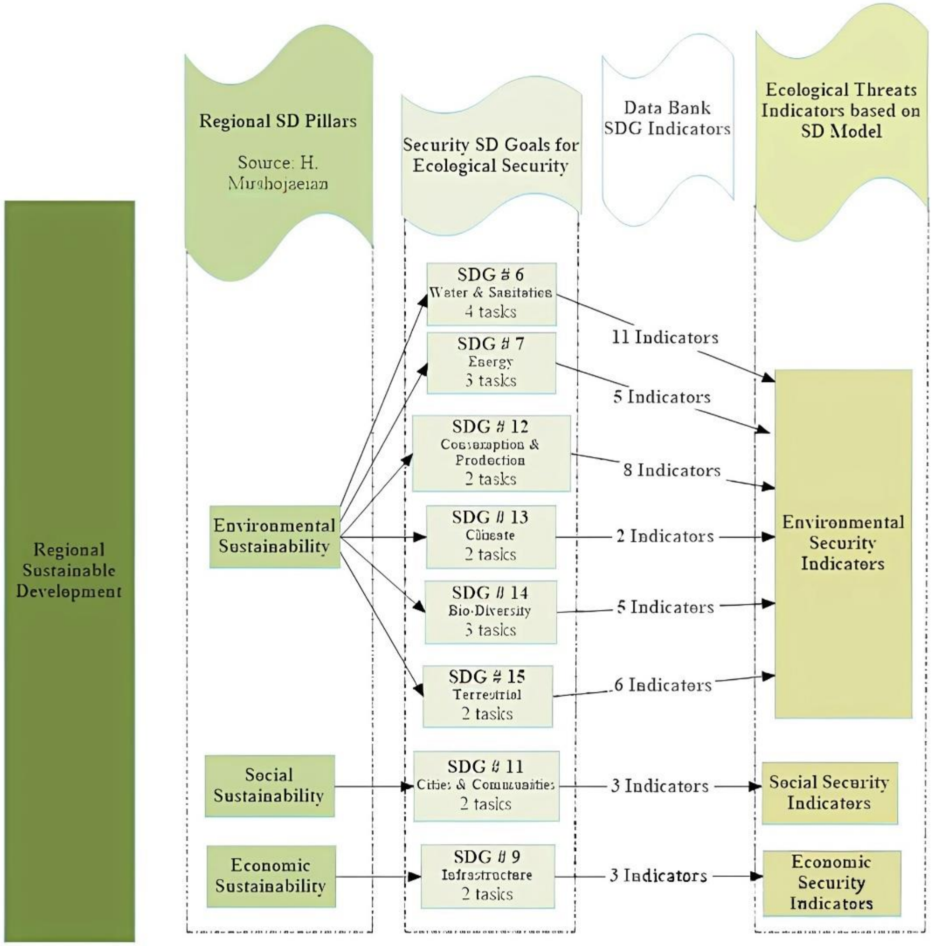


Fig. 2.2. Ecological Security Model (created by the author)
*The above Figure is available in the Zenodo link https://zenodo.org/records/15570821 file # 2. with better resolution

It starts with understanding the regional sustainable development goals to find the security of SDGs and build an ecological security model.

The model's method is based on selecting indicators for the eight discovered security SDGs that are responsible for securing SDGs and, accordingly, securing regional development against contemporary ecological threats.

Then, indicators that are related to the eight security SDGs are selected from the database available on the World Bank's databank, which is subject to the data availability of the selected indicators.

The originality of this SD model is that it lists 43 SD indicators to measure ecological security, which can be used to mitigate ecological threats to enhance regional SD, which presents the uniqueness of this model in considering the regional insecurities and utilising the creditable source of the World Bank in selecting the indicators from sustainable development database.

The purpose of this model is to serve as a framework for constructing a security management tool that measures countries' performance and can be used for countries' ranking based on theoretically grounded sustainable development parameters.

The model usage would allow policymakers to rate policy initiatives aimed at the same policy goals based on their effectiveness at getting the country on a sustainable development path.

2.2.4. Ecological Threat Indicators

The indicators extracted from the World Bank's website can be exported as a spreadsheet containing a table of 43 UNSD (United Nations Sustainable Development) indicators encompassing the eight goals, associated 20 targets, and the 43 attributed coded indicators related to mitigating the ecological threats.

Table 2.3 below lists the main ecological threats with descriptions related to eight security SDGs, the security targets, and the code of the goal and task. It also lists each ecological threat's SD pillar and theme categorisation.

Table 11. Forty-three ecological threat indicators based on SDGs (created by the author, retrieved from the World Bank's sustainability database)

No.	Main Ecological Threats	Security Targets	Security SD Tasks	Ecological Threats Indicators Description	Indicator SDG code (Goal. Task)	Indicator pillar, Theme
1	**Water insecurity**		Securing drinking water	People using at least basic drinking water services (% of the population)	6.1	Environmental, planet
				People using safely managed drinking water services (% of the population)		

Continued Table 2.3

No.	Main Ecological Threats	Security Targets	Security SD Tasks	Ecological Threats Indicators Description	Indicator SDG code (Goal. Task)	Indicator pillar, Theme
3				People practising open defecation (% of the population)		
4				People using at least basic sanitation services (% of the population)		
5				People using safely managed sanitation services (% of the population)		
6				People with basic handwashing facilities including soap and water (% of the population)		
7			Securing freshwater	Annual freshwater withdrawals, total (% of internal resources)	6.4	
8				Level of water stress: freshwater withdrawal as a proportion of available freshwater resources		
9				Renewable internal freshwater resources per capita (cubic meters)		
10				Water productivity, total (constant 2010 USD GDP per cubic meter of total freshwater withdrawal)		
11			Securing water-related ecosystem	Change in the extent of water-related ecosystems over time	6.6	
12	**Energy insecurity**	Stable, sustainable and accessible energy	Electricity accessibility and stability	Access to electricity (% of the population)	7.1	Environmental, prosperity
13				Access to clean fuels and technologies for cooking (% of the population)		
14			Renewable energy sustainability	Renewable electricity output (% of total electricity output)	7.2	

Continued Table 2.3

No.	Main Ecological Threats	Security Targets	Security SD Tasks	Ecological Threats Indicators Description	Indicator SDG code (Goal. Task)	Indicator pillar, Theme
15				Renewable energy consumption (% of the total final energy consumption)		
16			Energy intensity	The energy intensity level of primary energy (MJ/USD2011 PPP GDP)	7.3	
17	**Infrastructure Insecurity**	Efficient, safe, and healthy infrastructure	Transportation (Efficient and Safe)	Air transport, passengers carried	9.1	Economic, Prosperity
18			Transportation (Efficient and Safe)	Railways, passengers carried (million passenger-km)	9.1	
19			Healthy CO2 emissions reduction	CO2 emissions (kg per PPP USD of GDP)	9.4	
20	**City threats**	Safe and healthy cities	Minimise losses related to city disasters	Number of deaths, missing persons, and directly affected persons attributed to disasters per 100,000 population	11.5	Social, Prosperity
21				Direct economic loss in relation to global GDP, damage to critical infrastructure, and number of disruptions to basic services attributed to disasters		
22			Minimise environmental impact of cities, such as solid waste and pollution	PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	11.6	Social, Prosperity
23	**Resource consumption threats**	Sustainable ecosystem	Reduce ecological footprint	Adjusted net savings, excluding particulate emission damage (% of GNI)	12.2	Environmental, Planet
24				Coal rents (% of GDP)		
25				Forest rents (% of GDP)		
26				Mineral rents (% of GDP)		

End of Table 2.3

No.	Main Ecological Threats	Security Targets	Security SD Tasks	Ecological Threats Indicators Description	Indicator SDG code (Goal. Task)	Indicator pillar, Theme
27	Resource consumption threats			Natural gas rents (% of GDP)		
28				Oil rents (% of GDP)		
29				Total natural resources rents (% of GDP)		
30			Reduce fossil-fuel consumption	Number of sustainable tourism strategies or policies and implemented action plans with agreed monitoring and evaluation tools	12.8	
31	Climate change threats	A stable and safe climate	Control climate impact	Droughts, floods, extreme temperatures (% of the population, average 1990–2009)	13.1	Environmental, planet
32			Augment disaster risk reduction, such as GHG emissions and geoengineering impacts	Disaster risk reduction progress score (1–5 scale; 5=best)	13.2	
33	Aqua insecurity	Sustainable production and threat prevention on aqua systems	Coastal ecosystem SD	The proportion of national exclusive economic zones managed using ecosystem-based Approaches	14.2	Environmental, planet
34			Aqua production	Aquaculture production (metric tons)	14.4	
35				Capture fisheries production (metric tons)		
36				Total fisheries production (metric tons)		
37			Marine protection	Marine protected areas (% of territorial waters)	14.5	
38	Biodiversity insecurity	Sustainable production and threats prevention of biodiversity systems	Terrestrial conservation	Forest area (% of land area)	15.1	Environmental, planet
39				Terrestrial and marine protected areas (% of total territorial area)		
40				Terrestrial protected areas (% of total land area)		
41			Biodiversity extinction	Fish species threatened	15.5	
42				Mammal species threatened		
43				Plant species (higher) threatened		

Table 2.4. Legend table related to Table 2.3

Colour coding	Indicator data Availability in World Bank databases	Quantity
(grey)	N/A	5
(green)	Available but not recorded	2
	Available	**36**

*The above table is available in the Zenodo link https://zenodo.org/records/15570821 file # 2.

The legend table is based on the retrieved data from the World Bank's databank for G20 countries, which shows five unavailable indicators highlighted in grey. Two available indicators with no available data are highlighted in green (Chehabeddine et al., 2023).

2.3. Conclusions of the Second Chapter

The argument is about having a model that considers the impact of the new regional insecurities on the SDGs' perspective. The built ecological security model is based on securing SDGs against ecological threats that harm regions by identifying the security facets of concerned SDGs related to these ecological threats and then measuring their ecological performance for the identified security indicators.

1. The existing studies have mainly focused on reviewing and comparing the results of conventional indicators to measure sustainable development, such as the ecological footprint and human development (Li et al., 2022). However, they do not measure the harm of ecological threats to regional development. They do not consider securing SD related to these ecological threats based on the security aspects of the SDGs.
2. The model's method is based on selecting indicators for the eight discovered security SDGs that are responsible for securing SDGs and, accordingly, securing regional development against contemporary ecological threats.
3. The uniqueness of this model lies in utilising the credible source of indicators from the World Bank databank in selecting the indicators from the sustainable development database since the indicators were filtered from 1443 available in the World Bank into 404 SD indicators and then to 43 security SD indicators according to eight security SDGs.
4. The findings should be viewed as a comparative indicator of sustainable development performance and a tool for identifying policy issues that need to be addressed; therefore, the purpose of this model is to serve as a framework for constructing a security management tool that measures

countries' performance and can be used for countries' ranking based on theoretically grounded sustainable development parameters.

5. The created security model contributed to the management science in integrating security principles into sustainable development to mitigate the ecological threats facing the G20 group, in which regional planners and policymakers rate policy initiatives aimed at the same policy goals based on their effectiveness at getting the country on a sustainable development path, and then can foster secure, sustainable development, improve quality of life, and enhance economic resilience for regions.
6. The security SD model shifts from value-added to core aspects by integrating security principles through embracing all spectrums of contemporary global threats to ensure the interconnectivity of security with the 17 SDGs, considering these ecological threats, especially those that threaten the eight security SDGs, to fill the insecurity gap, and assisting us in constructing the global ecological security tool.
7. Shifting from value-added refers to moving the focus from merely enhancing economic outputs to addressing fundamental issues that underpin sustainable development. It involves prioritising core aspects such as:
    - Environmental protection – ensuring natural resources are preserved and ecosystems are maintained.
    - Social equity – promoting fairness and equal opportunities for all individuals.
    - Economic stability – building resilient economies that can withstand global challenges.
    - Security integration – incorporating security measures to address global threats like climate change, pandemics, and geopolitical tensions.

Limitations

The collection of indicators is limited to selecting indicators related to ecological threats threatening SD goals; moreover, the indicators could be extracted from databases other than the World Bank. The data of a few extracted indicators are unavailable for some countries; therefore, the result is subject to several uncertainties and qualifications, where knowledge gaps and measurement issues cause uncertainty that warrants further expert consultation.

Future Improvement

All indicators, particularly for developing nations, are hampered by the poor quality and coverage of available data, inconsistent techniques, weak time series, and major gaps. Governments must acknowledge that data collection is primarily their duty. Investing in data collection pays off handsomely in terms of better decision-making. However, using the most recent methodology and data, it is possible to compute an ecological security tool for earlier years to begin measuring relative performance between nations and how each country's performance changes over time.

3

Constructing an Ecological Security Management Tool

This chapter aims to construct a novel management tool focusing on the ecological security aspects of eight sustainable development goals (SDGs). The tool construction is based on the sustainable development (SD) security model that measures ecological security in the regions. The ultimate goal is to construct a tool to manage facets of sustainable development. The research study is focused on the G20 countries. The World Bank's databank was utilised to get secondary data on selected security indicators. The methodological approach relies on grouping ecological security indicators (clustering using the k-means method) and studying the indicators' characteristics. Accordingly, it relies on cluster relationships to find the main cluster that would obtain a structured system of indicators (critical indicators have a high impact on the whole system) and weighting the system of indicators using experts. It is based on sustainability aspects, suitable for constructing a novel measurement tool using the multiple criteria decision-making TOPSIS method that selects the best alternative from a set of alternatives according to several criteria that allow evaluating and ranking the ecological security level for each of the G20 countries and managing the processes through relevant economic policies, depending on each country's rules and regulations. The connections between the subchapters below started from data mining, clustering the obtained system of indicators, identifying the main cluster, which will be evaluated by the experts to construct a management tool and then finding the best alternative using TOPSIS to rank the ecological security levels for G20 countries.

Sub-chapter 3.5 provides the results of ecological security performance for the G20, showing low scores in the security indicators related to sustainability.

The decision-makers of each country will take the proposed mitigation actions according to each country's policies, rules, and regulations.

Saudi Arabia (a member of the G20 countries) was chosen as an example of the applications to apply the created management tool at the end of the dissertation.

One publication was published on the topic of this chapter (Chehabeddine, Tvaronavičienė, & Zinkevic, 2023).

3.1. Data Collection and Analysis

The threats to sustainable development are sufficiently diverse. Countries need standardised and trustworthy indicators to monitor and assess their growth (Krishna et al., 2018).

The study focuses on measuring ecological security, and the selected research object is the G20 countries.

The G20 is made up of 19 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Mexico, Saudi Arabia, South Africa, Russia, Turkey, the UK, and the USA, and one regional body: the European Union.

The results for the G20 countries show that they can be categorised into three main groups after being ranked according to their ecological security performance.

After selecting eight security SDGs, the targeted G20 group countries, and the targeted period from 2010 to 2019 using the World Bank's database, the security indicators and their data can be extracted, as shown in Figure 3.1 below.

G20 countries were chosen because they are the leading countries with a high green development level (Shao et al., 2022) and control two-thirds of the world's economies.

G20 countries have similar characteristics regarding regional development goals in addressing significant issues related to the global economy and sustainability, such as climate change mitigation and sustainable development, through annual meetings of heads of state and heads of government.

The G20 plays a significant role in shaping global economic policies and fostering cooperation among its member nations on various critical issues.

The criticality of this group came from the fact that they control 85% of the global gross domestic product (GDP), over 75% of world trade, and approximately two-thirds of the global population(G20 Members – G20 South Africa, n.d.). Consequently, the impact of securing the regional development of the G20 will be worldwide.

Fig. 3.1. Ecological security indicators for G20 using World Bank's data (Sustainable Development Goals (SDGs) | DataBank, n.d.).

* Refer to Figure 3.1 in the Zenodo link https://zenodo.org/records/15570821 file # 3, for better figure resolution.

The security indicator measurements of each G20 country are identified based on an SD ecological security model. These are related to securing sustainable development goals, retrieved from the World Bank since these data on the indicators are related to the eight security SDGs and can be retrieved from the World Bank's databank. It can be processed on the same website or exported to a spreadsheet for further processing (Sustainable Development Goals (SDGs), n.d.).

All these data are available for G20 countries; however, the World Bank's data on indicators are available until 2019.

It was found that 34 out of 43 indicators available for G20 countries are used in constructing the SD security management tool. The reduction of the indicators came from unavailable indicators or missing data for more than 25% of the total data. The obtained security indicators are chosen from the SDGs database of databank, addressing the impact of ecological threats (Krishna et al., 2020). These indicators can form an effective ecological security tool for evaluating sustainability, which may be instrumental in measuring G20 countries' ecological security and managing the processes through relevant economic policies; however, integrating key sustainability indicators is essential for decision-making.

These indicators need to be normalised first and used to estimate weights based on the weighting of the indicator, e.g., based on PCA. Conversely, they need to be based on expert opinion, which is highly subjective. This study's indicators were shortlisted by a two-step process: principal component analysis and linear and non-linear weighted scores (Krishna et al., 2020).

The processes of the shortlisting of 15 security indicators out of 1443 will be explained in gradual steps, showing how these indicators are filtered into 404 sustainable development indicators, then into 43 security SD indicators, then into 35 security SD indicators that have available data for G20 to be studied, and then into 15 critical indicators of security SD indicators for G20 countries.

3.1.1. Dimension Analysis

Dimension analysis looks at the relationships between indicators to find the most important ones and reduce the number of dimensions. In reality, the relationships between the measured events can only sometimes be reflected in the correlations between indicators.

Therefore, it studies correlation indicators to determine the critical indicators to reduce the dimensionality. Correlations among indicators might not correspond to the real-world links between the measured phenomena.

The homogenous analysis can handle a variety of different types of indicators. It may be used if the indicators do not strongly correlate and do not suggest weight manipulation through ad hoc restrictions. The system's limitation is the linear behaviour assumption between the indicators and the composite. Data is also needed to generate estimates with well-known statistical features. It can be used if only the indicators are not highly correlated and do not imply any weight manipulation through ad hoc restrictions. However, the drawback of the system is the assumption of linear behaviour between indicators and the composite. It also requires much data to produce estimates with known statistical properties.

The variables (data) gathered under each category of ecological security, economic efficiency, and social equality may be correlated with one another, a phenomenon known as multi-collinearity, which can be used to reduce the data dimensionality. To minimise the dimensionality of the data in the current study while keeping the majority of the variability found in the original data, principal component analysis (PCA) was applied. Consequently, PCA was utilised in the current study to decrease the dimensionality of the data while maintaining the majority of the variability found in the original data (Krishna et al., 2020). This study employed PCA to choose a small number of indicators to visualise objects in a two-dimensional space to study the trend better. Furthermore, a weighted indicator was developed using the linear and non-linear scoring functions to gauge sustainability.

Not all indicators may contribute equally to the intended sustainability measurement. The contribution of an indicator could be positive or negative. Hence, each indicator was normalised to be measured on a standard scale. The indicators were combined with a weight based on their relative importance using a non-linear weighted scoring system to provide a clear picture of the situation. In many research studies, a weighted score ecological security tool determines the indicator's relative value (Krishna et al., 2020). Not all indicators have the same impact on the result; an indicator's impact may be positive or negative.

3.2. Clustering Methodology

The clustering methods were used to segregate the security indicators into different aspects, where PCA was used to reduce the dimensionality of the data (Krishna et al., 2020).

After obtaining the data indicators and then describing, interpreting, and clustering them, it was found that some critical indicators significantly impact the whole system, as observed by analysing their data qualitatively and quantitatively after clustering; these critical SD security indicators can be re-grouped according to different aspects of sustainable development.

The study demonstrates two data indicator analysis methods. It searches for the indicator's relationship for each cluster by analysing the indicator's occurrence and its positions on the 2D graph.

Afterwards, the clustered indicators will be re-grouped according to new aspects to obtain a combination of critical indicators. Then, the country's re-grouping factors will be applied to each cluster based on its sustainable development level.

Generally, there were two types of clustering:

- clustering of countries and
- clustering of indicators (criteria).

3.2.1. Clustering of Countries

The procedure for country clustering is as follows:

- Processing initial data.
- Removing all criteria that contain missing data.
  - It is required to determine the indicators with data missed by more than 75% that cannot be restored and need to be removed, such as

indicators 11, 25, 27, and 39, which were removed. In contrast, indicators with less than 25% of their data missed can be utilised after restoration (indicators 1, 12, 26, and 30 were restored, seven values in total), constructing an array of countries against indicators [35 rows x 20 columns].

Data normalisation

– Applying the k-means method determines the optimal number of clusters with the elbow method (by the curve).
– The deployed clustering method is k-means, which could predict a different number of clusters by analysing the elbow locations on the graph and determining the optimal number of clusters; then, PCA can be implemented using the graphical representations of clusters in two-dimensional space.
– Start by varying the number of clusters (K) from 1 to 10, calculating WCSS (within-cluster sum of squares) for each value of K. WCSS is the sum of the squared distance between each point and the centroid in a cluster.
– Plotting the WCSS with the K value will provide a plot that looks like an elbow. As the number of clusters increases, the WCSS value will start to decrease. The WCSS value is largest when K = 1. Until the graph rapidly changes to a point that creates an elbow shape. From this point, the graph begins to move almost parallel to the x-axis. The K value corresponding to this point is the optimal K value or the optimal number of clusters (Elbow Method to Find the Optimal Number of Clusters in K-Means, n.d.).
– A curve is drawn for n clusters from 2 to 14. An explicit transition is seen at points 3 and 9. The optimal number of clusters is 3 or 9, as shown in Figure 3.2.

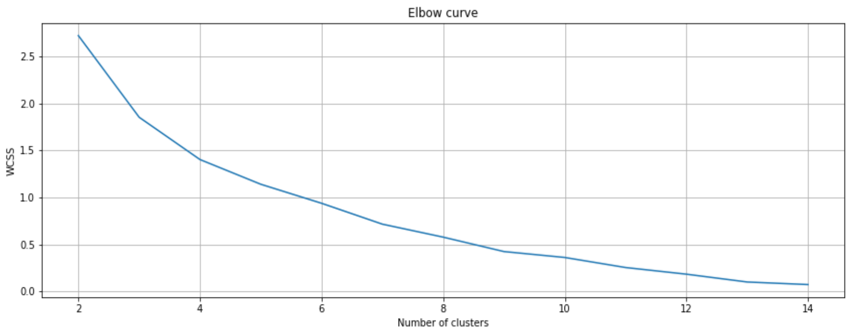


Fig. 3.2. Optimal number of clusters for clustering of countries (created by the author)
* Refer to Figure 3.2 in the Zenodo link https://zenodo.org/records/15570821 file # 3, for better figure resolution.

Table 3.1. G20 countries in a sequence to apply k-means clustering (created by the author)

Country number	Country number	Country number	Country number
1	Saudi Arabia	11	India
2	Argentina	12	Mexico
3	Australia	13	Russian Federation
4	Brazil	14	South Africa
5	Canada	15	Turkey
6	France	16	United States
7	Germany	17	United Kingdom
8	Italy	18	Korea, Rep.
9	Japan	19	China
10	Indonesia	20	European Union

The result of clustering G20 countries listed in Table 3.1 is to be clustered into 3 and 9 clusters as follows:

For countries with 3-clustering: The resulting array of data division into 3 clusters is [1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 0], where the number of clusters is the highest value in the array plus one since the clusters start from zero.

According to the above Table 3.1, for the countries order, the countries of the 3 clusters will be as follows:

1. Argentina, Australia, Brazil, Canada, France, Germany, Italy, Japan, Indonesia, India, Mexico, Russian Federation, South Africa, Turkey, United States, United Kingdom, Korea Rep., and the European Union
2. Saudi Arabia
3. China

Similarly, the result array of data division into 9 clusters is [1 2 8 0 0 2 2 2 2 7 5 2 4 8 2 2 2 2 3 6]

For countries with 9-clustering (suitable clustering for countries):

According to the above Table 3.1, for the countries order, the countries of the 9 clusters will be as follows:

1. Brazil, Canada
2. Saudi Arabia
3. Argentina, France, Germany, Italy, Japan, Mexico, Turkey, United States, United Kingdom, and Korea Rep.
4. China

5. Russian Federation
6. India
7. European Union
8. Indonesia
9. Australia, South Africa

Applying the principal component analysis (PCA) method using a graphical representation of clusters in two-dimensional space, as shown in Figure 10 below, The PCA method reduces the number of features to two components since such data reduction may somewhat fix the results.

Obtaining an array of PCA data array an array of [2 rows x 20 columns], The resulting array of PCA data division into 3 clusters is [0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 1], where the number of clusters is the highest value in the array plus one since the clusters start from zero.

According to the above Table 3.1, for the countries order, the countries of the 3 clusters will be as follows and as shown in Figure 11, available in the Zenodo link https://zenodo.org/records/15570821 file # 3 :

1. Saudi Arabia
2. Argentina, Australia, Brazil, Canada, France, Germany, Italy, Japan, Indonesia, India, Mexico, Russian Federation, South Africa, Turkey, United States, United Kingdom, Korea Rep., and the European Union
3. China

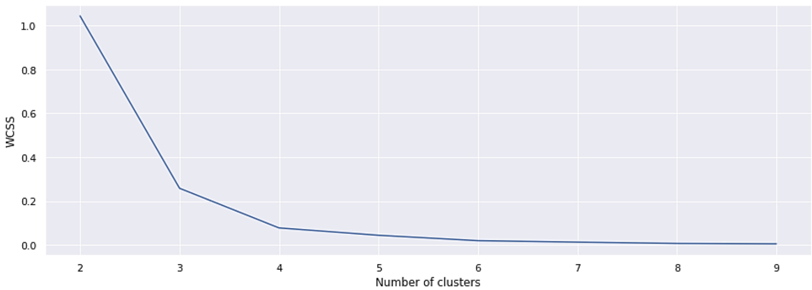


Fig. 3.3. Elbow curve after PCA application for countries (created by the author)
* Refer to Figure 3.3 in the Zenodo link https://zenodo.org/records/15570821 file # 3, for better figure resolution.

The plotting of G20 countries into three clusters in the PCA data division (Source: created by the author) is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.4.

The resulting array of PCA data division into nine clusters is [1 3 3 6 7 7 7 7 6 4 4 3 5 8 3 6 7 3 2 0], where the number of clusters is the highest value in the array plus one since the clusters start from zero.

According to the above Table 3.1, for the countries order, the countries of the nine clusters will be as follows and as shown in Figures 3.5 and 3.6:

1. European Union
2. Saudi Arabia
3. China
4. Argentina, **Australia**, Mexico, Turkey, Korea Rep
5. **Indonesia**, India
6. Russian Federation
7. **Brazil**, Japan, and the United States
8. **Canada**, France, Germany, Italy, United Kingdom
9. South Africa

Highlighted in bold font are the differences between 9-clustering countries without PCA and with PCA, whereas the nine clusters by original data without PCA of 35 criteria are as follows:

1. Brazil, Canada
2. Saudi Arabia
3. Argentina, France, Germany, Italy, Japan, Mexico, Turkey, United States, United Kingdom, and Korea Rep.
4. China
5. Russian Federation
6. India
7. European Union
8. Indonesia
9. Australia, South Africa

The clustering plotting of G20 countries into nine clusters in the PCA data division (Source: created by the author) is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.5.

The clustering plotted with zooming of G20 countries into nine clusters in the PCA data division (Source: created by the author) is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.6.

As mentioned earlier, according to the sustainable development level, G20 countries are divided into four groups (developing, low-developed, middle-developed, and high-developed).

By comparing the clustering of K-means of 9-clustering to the four groupings, it is found that clusters (4, 6, 8) fall in the developing countries highlighted in red colour. Cluster (5) falls in the Low developed countries highlighted in orange colour, Cluster (2) falls in the middle developed countries highlighted in yellow colour, and Clusters (1, 3, 7, 9) fall in the high-developed countries highlighted in green colour as shown in Table 3.2, where the country development category was retrieved from Table 1.10.

Table 3.2. G20 clustering categorisation (created by the author)

SN	G20 Country	Country Development Category	Clustering# of 9 Clusters	Cluster Category	Location on Graph	Location Quadrant
1	China	Developing	4	4,6,8	19	Left upper quadrant
2	India		6		11	Left upper quadrant
3	Indonesia		8		10	Left upper quadrant
4	Brazil		1		4	Left lower quadrant
5	South Africa		9		14	Left centre
6	Russia	Low-developed	5	5	13	Right centre
7	Argentina		3		2	Centre bottom
8	Mexico		3		12	Centre bottom
9	Saudi Arabia	Middle-developed	2	2	1	Right upper quadrant
10	Turkey		3		15	Centre bottom
11	Japan	High-developed	3	3,9,1,7	9	Centre bottom
12	South Korea		3		18	Centre bottom
13	Australia		9		3	Centre bottom
14	Canada		1		5	Centre bottom
15	USA		3		16	Centre bottom
16	France		3		6	Centre bottom
17	Germany		3		7	Centre bottom
18	Italy		3		8	Centre bottom
19	United Kingdom		3		17	Centre bottom
20	European Union		7		20	Centre

The plotting of G20 clustering categorisation (created by the author) is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.7.

The last column shows the location of each country/cluster on the above graph, along with their SD level colour.

It was found that the clusters above the zero level in the left top quadrant are developing countries, whereas the clusters under the zero level in the left bottom are developed countries, as shown in Figure 3.7, available in the Zenodo link https://zenodo.org/records/15570821, file # 3. Furthermore, the cluster that approaches zero in the horizontal line belongs more to developed countries, as shown below:

- D4: developing G20 countries' clusters (4, 6, and 8).
- D3: semi-developing G20 countries' cluster (5).
- D2: semi-developed G20 countries' cluster (2).
- D1: developed G20 countries' clusters (1, 3, 7, and 9).

The above grouping shows that the countries' development status is related to countries clustering, which guides us to consider the countries' commonalities, which could be used to recommend high cooperation and collaboration between the same clustered countries for better ecological security results.

3.2.2. Clustering of Indicators

The clustering of indicators assists in understanding their distribution and characteristics, creating a system of indicators for experts to develop an accurate management tool that can measure the ecological security of the country's sustainable development.

The following points are followed to get the clustering of indicators:

1. Ecological threat indicators are retrieved from the World Bank and described in terms of security targets (vulnerability), tasks, indicators, themes, and availability.
2. The SD model for ecological threats is utilised to get SDG indicators.
3. Thirty indicators have complete data, and data from four indicators can be recovered. In contrast, Indicator 6 is omitted because of limited data years (just 2018 for all countries), so it is removed, which leads to having 34 indicators that can be clustered.
4. Metadata that provides a long definition and source, as well as limitations and useful links, were retrieved from the World Bank, except for two indicators that were retrieved from UN.org.
5. Clustering methods are divided into (3, 6, and 9) clusters (6 and 9 after PCA) and sequenced as per the order of SDGs.
6. Clustering breakdown according to the SDGs security indicator reference.
7. Plotting a 2D graphical representation for the clustered data.
8. Clustering distribution and analysis for the data indicators.

Table 2.3 lists 43 security indicators, their sustainability pillar, and the targeted change direction. For maintaining the security targets under eight security SDGs (water, energy, infrastructure, cities, resource consumption, climate change, aquatic systems, and biodiversity), these indicators need to be redefined according to clustering results to create a management tool that can measure the ecological security of the regional ecosystem.

Many methods can be used to choose an indicator system. The weighting of indicators can be subjective, based on the expert opinions on the literature review. For clustering, data must be available, but it has been found that some data cannot be obtained from the databank.

Similar to what was done in country clustering, the adopted strategy for data collection starting from the available 36 indicators is listed in Table 2.3.

The indicators for which data could not be restored were removed. Indicators with more than 75% missed data were removed from the list. Hence, nine were removed from the selected 43 indicators. Indicators (11, 25, 27, and 39) were removed, in contrast to indicators that have less than 25% of their data missed, which can be utilised after restoration, such as Indicators (1, 12, 26, and 30) in Table 2.3, were restored, constructing an array of countries against indicators (seven values in total) [20 rows x 35 columns].

Due to the similarity and compliance with the redundancy of indicators, it is sufficient to merge and include one of the following security indicators in the study instead of both. The indicator “People using at least basic drinking water services (% of the population)” supersedes the indicator “People using safely managed drinking water services (% of the population)”, so the second one will be removed. Similarly, the indicator “People using at least basic sanitation services (% of the population)” supersedes “People using safely managed sanitation services (% of the population),” so the second one will be removed. However, the indicator “Bird species, threatened” was added to the list to cover all the remaining live ecosystems. Therefore, the total number of indicators is 35, as shown in Table 3.2, after removing two similar indicators and adding one indicator, as mentioned above, to the available 36 indicators. To research these indicators effectively, it is recommended to cluster them based on the data indicators obtained from the World Bank’s databank since the scope is G20 countries; however, some data cannot be obtained from the databank; therefore, some indicators were removed due to limited or no data availability.

It is necessary to study the data indicators obtained after clustering them to build a system of indicators.

Table 3.3. Descriptions of 35 security indicators as per World Bank (created by the author)

35 Indicators	Security Indicator description
1	Access to clean fuels and technologies for cooking (% of the population)
2	Access to electricity (% of the population)
3	Adjusted net savings, excluding particulate emission damage (% of GNI)
4	Air transport, passengers carried
5	Annual freshwater withdrawals, total (% of internal resources)
6	Bird species are threatened.
7	Aquaculture production (metric tons)
8	Capture fisheries production (metric tons)
9	CO_2 emissions (kg per PPP $ of GDP)
10	Coal rents (% of GDP)
11	The energy intensity level of primary energy (MJ/USD 2011 PPP GDP)
12	Fish species threatened
13	Forest area (% of land area)
14	Forest rents (% of GDP)
15	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
16	Mammal species threatened
17	Mineral rents (% of GDP)
18	Oil rents (% of GDP)
19	Natural gas rents (% of GDP)
20	Marine protected areas (% of territorial waters)
21	People practising open defecation (% of the population)
22	People using at least basic drinking water services (% of the population)
23	People using at least basic sanitation services (% of the population)
24	People using safely managed sanitation services (% of the population)
25	Plant species (higher) threatened
26	PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total)
27	Railways, passengers carried (million passenger-km)
28	Renewable electricity output (% of total electricity output)
29	Renewable energy consumption (% of total final energy consumption)
30	Renewable internal freshwater resources per capita (cubic meters)
31	Terrestrial and marine protected areas (% of total territorial area)
32	Terrestrial protected areas (% of total land area)
33	Total natural resources rents (% of GDP)
34	Total fisheries production (metric tons)
35	Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)

The K-means clustering (K-means) method is one of the most popular methods in data analysis and machine learning. It is used to divide a data set into clusters so that objects within one cluster are more similar than objects in other clusters. The k-means method starts with the initial idea that the mean values of the objects in each cluster (centroids) are the best representatives for that cluster. The elbow method is often used to determine the optimal number of clusters in the k-means method. This method involves running the k-means algorithm with different values of K (number of clusters) and estimating the intra-cluster variance (within-cluster sum of squares, WCSS metric) for each value of K. The WCSS is then plotted against the number of clusters. Visually, one can often observe an "elbow" on the graph, where WCSS decreases with less intensity. This value of K corresponds to the optimal number of clusters for a given dataset.

Starting by varying the number of clusters (K) from 1 to 10 for the obtained security indicators provided in Table 2.3, calculating WCSS (within-cluster sum of squares) for each value of K, the sum of the squared distances between each point and the cluster's centroid. A plot resembling an elbow will result from plotting the WCSS with the K value. The WCSS value will begin to drop as the number of clusters rises. The highest WCSS value is at K = 1. Until the graph rapidly changes to the point that it creates an elbow shape. The graph then starts to travel nearly parallel to the x-axis from this point on. The best K value, or the most clusters, is the one that corresponds to this location.

A curve is drawn for K clusters from 2 to 10. An explicit transition is seen at points 3 and 9; the graph shows a clear elbow point in cluster number 6, as shown in Figure 3.8.

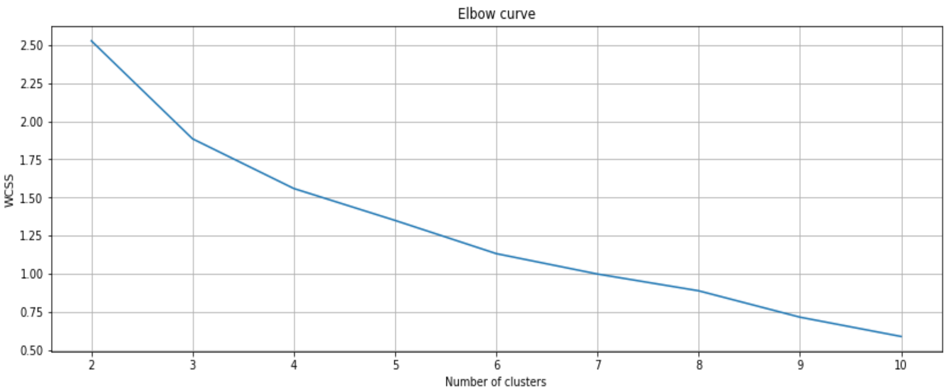


Fig. 3.8. Elbow curve with clustering of six (Source: created by the author)
* Refer to Figure 3.8 in the Zenodo link https://zenodo.org/records/15570821 file # 3, for better figure resolution.

Table 3.4. Clusters of indicators (Source: created by the author)

Cluster	**Indicator Number according to World Bank**	**Indicator**	**Indicator characteristic**	**Cluster Summary**
1	**2**	**3**	**4**	**5**
C1 (18 indic.)	13	Access to clean fuels and technologies for cooking (% of the population)	Green energy	Green energy use, the health of forests and water, economic gain composition from using natural and renewable resources Cluster 1. Green infrastructure and human health
	12	Access to electricity (% of the population)	Energy security	
	23	Adjusted net savings, excluding particulate emission damage (% of GNI)	Green savings	
	19	CO_2 emissions (kg per PPP $ of GDP)	Pollution	
	16	The energy intensity level of primary energy (MJ/$2011 PPP GDP)	Pollution	
	38	Forest area (% of land area)	Level of resources used for restoration from pollution	
	37	Marine protected areas (% of territorial waters)	Level of resources used for restoration from pollution	
	1	People using at least basic drinking water services (% of the population)	Maintaining Health	
	3	People using at least basic sanitation services (% of the population)	Level of water quality preservation	
	5	People using safely managed sanitation services (% of the population)	Level of water quality preservation	

Continued Table 3.4

1	2	3	4	5
	43	Plant species (higher), threatened	Health of plants	
	22	PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total)	Minimise air pollution (exceeding some set guidelines)	
	14	Renewable electricity output (% of total electricity output)	Green energy percentage	
	15	Renewable energy consumption (% of total final energy consumption)	Green energy percentage	
	9	Renewable internal freshwater resources per capita (cubic meters)	The health of water	
	39	Terrestrial and marine protected areas (% of total territorial area)	The health of water	
	40	Terrestrial protected areas (% of total land area)	The health of forests and plants	
	10	Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)	The health of water resources	
C2 (1 Indic.)	2	People practising open defecation (% of population)	Maintaining Health(Pollution of water)	People practising open defecation related to maintaining health Cluster 2: It is embedded within Cluster 1
C3 (4 Indic.)	7	Annual freshwater withdrawals, total (% of internal resources)	Maintaining Health (deterioration of fresh water)	Deterioration of natural resources (freshwater) is caused by using natural resources. Cluster 3: Ecological Degradation caused by natural resources use
	8	Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	Maintaining Health	
	28	Oil rents (% of GDP)	Economic rents (oil rents are	

Continued Table 3.4

1	2	3	4	5
			gains received from oil for the deterioration caused by the use of natural resources)	
	29	Total natural resources rents (% of GDP)	Economic rents embracing coal and gas rents	
C4 (3 Indic.)	34	Aquaculture production (metric tons)	The health of water resources	Sustainable aqua life, transportation Cluster 4: Health of aquacultures
	18	Railways, passengers carried (million passenger-km)	Green Transportation	
	36	Total fisheries production (metric tons)	Sustainable aqua life	
C5 (6 Indic.)	17	Air transport, passengers carried	Polluting transport	Deterioration of life in air, water, and air transport pollution. Cluster 5: Air Transportation Threats
	X (only indicator data available is for 2018 for all countries)	Bird species threatened	The health of the environment	
	19	CO2 emissions (kg per PPP USD of GDP)	Pollution level	
	41	Fish species threatened	Aqua life threats	
	42	Mammal species threatened	Aqua life threats	
	43	Plant species (higher), threatened	Aqua life threats	

End of Table 3.4

1	2	3	4	5
C6 (3 Indic.)	24	Coal rents (% of GDP)	Enhancing GDP (Pollution)	Economic rents from deterioration of natural resources Cluster 6: Economic rents threaten natural resources
	25	Forest rents (% of GDP)	Enhancing GDP (Pollution)	
	26	Mineral rents (% of GDP)	Enhancing GDP (Pollution)	

Note: In Table 3.4, the indicators are ordered according to the World Bank numbering, which is followed in the below clustering.

The results of the clustering of six are shown in the array. The below array data resulted from the k-means method, where the number of clusters is the highest number in the array plus one since the clusters start from zero. Clustering of six: [0 0 0 4 2 4 3 4 0 5 0 4 0 5 2 4 5 2 0 0 1 0 0 0 4 0 3 0 0 0 0 0 2 3 0].

The division into a plot of six clusters (Source: created by the author) is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.9, shows a graphic representation of clusters in a two-dimensional space.

Data reduction was applied using the PCA method to reduce the data array or the independent set.

The principal components are eigenvectors of the data's array (covariance matrix). The principal components are computed by the eigendecomposition of the data array. PCA can be considered to fit the variable-dimensional ellipsoid to the data. Biplots and scree plots (degree of explained variance) are used to interpret the findings of the PCA.

The elbow of the curve (bend in the ellipsoid) indicates the number of clusters to be retained. According to Figure 3.10 below and available in the Zenodo link https://zenodo.org/records/15570821 file # 3, six clusters will be explained.

As a result, sustainable development security indicators were attributed to six clusters, as shown in Table 3.4 above, and analysed accordingly in Table 3.5.

The clustering of indicators assists in understanding their distribution and characteristics to create a system of indicators for experts to weigh the indicators to have an accurate ecological security tool that can measure the security of the country's sustainable development.

Similarly, clustering with PCA data reduction starts by varying the number of clusters (K) from 1 to 10, calculating WCSS (within-cluster sum of square) for each value of K.

Table 3.5. Indicator topic as per metadata listed in the World Bank's databank (Source: created by the author)

Indicator topic as per metadata listed in the World Bank's databank							
#	**Qty**	**Indicator Numbers**	**Indicator Description**				
			1	**2**	**3**	**4**	
C1	18	13,12,23,19,16,38,37,1,3,	Environment: Energy production & use	Environment: Energy production & use	Economic Policy & Debt: National accounts: Adjusted savings & income	Environment: Emissions	
			5	**6**	**7**	**8**	**9**
			Environment: Energy production & use	Environment: Land use	Environment: Biodiversity & Protected areas	Health: Disease prevention	Health: Disease prevention
		5,43,22,14,15,9,39,40,10	**10**	**11**	**12**	**13**	
			Health: Disease prevention	Environment: Biodiversity & protected areas	Environment: Emissions	Environment: Energy Production & use	
			14	**15**	**16**	**17**	**18**
			Environment: Energy production & use	Environment: Freshwater	Environment: Biodiversity & protected areas	Environment: Biodiversity & protected areas	Environment: Freshwater

#	**Qty**	**Indicator Numbers**	**1**
C2	1	2	Health: Risk factors

#	**Qty**	**Indicator Numbers**	**1**	**2**	**3**	**4**
C3	4	7,8,28,29	Environment: Freshwater	Environment: Freshwater	Environment: Natural resources contribution to GDP	Environment: Natural resources contribution to GDP

#	**Qty**	**Indicator Numbers**	**1**	**2**	**3**
C4	3	34,18,36	Environment: Agricultural production	Infrastructure: Transportation	Environment: Agricultural production

End of Table 3.5

#	Qty	Indicator Numbers	1	2	3
C5	6	17, X,19,41,42, 43	Infrastructure: Transportation	Environment: Biodiversity & protected areas	Environment: Emissions
			4	**5**	**6**
			Environment: Biodiversity & protected areas	Environment: Biodiversity & protected areas	Environment: Biodiversity & protected areas

#	Qty	Indicator Numbers	1	2	3
C6	3	24,25,26	Environment: Natural resources contribution to GDP	Environment: Natural resources contribution to GDP	Environment: Natural resources contribution to GDP

*Refer to the Zenodo link https://zenodo.org/records/15570821 file # 3, Table 3.5, for further details on the metadata indicator (Chehabeddine, Tvaronavičienė & Zinkevic, 2023).

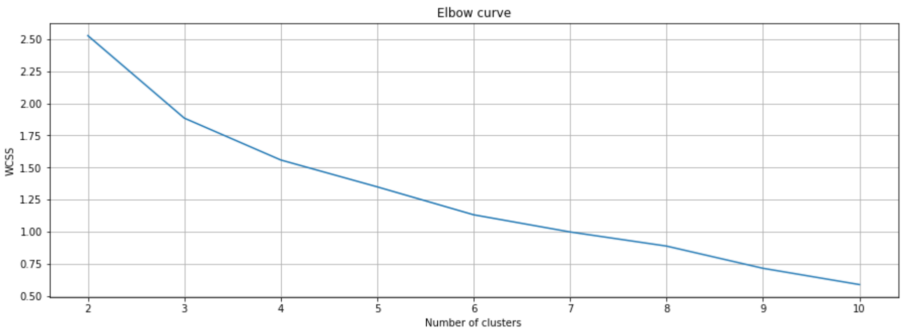


Fig. 3.10. Elbow curves after PCA application for indicators
(Source: created by the author)

WCSS is the sum of the squared distance between each point and the centroid. Plotting the WCSS with the K value will provide a plot that looks like an elbow. As the number of clusters increases, the WCSS value will start to decrease. WCSS value is largest when K = 1. Until the graph rapidly changes to a point that creates an elbow shape. From this point, the graph begins to move almost parallel to the X-axis. The K value corresponding to this point is the optimal K value or an optimal number of clusters.

A curve is drawn for n clusters, from 2 to 20. An explicit transition is seen at points 3 and 9.

The optimal number is 3, 6, and 9 clusters, their plots are available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.10, which shows a clear elbow point in Cluster 6.The results of the 3, 6, and 9 clustering for the criteria are shown in the arrays below.

The array data below resulted from the k-means method, where the number of clusters is the highest number in the array plus one since the clusters start from zero:

Clustering of three: [0 0 0 0 1 0 2 2 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 0 2 0 0 0 0 0 1 2 0]

Clustering of six: [0 0 0 4 2 4 3 4 0 5 0 4 0 5 2 4 5 2 0 0 1 0 0 0 4 0 3 0 0 0 0 0 2 3 0]

Clustering of nine: [1 1 1 2 3 2 4 2 1 0 1 2 1 0 3 2 0 3 5 7 6 1 1 1 2 1 0 1 1 8 7 7 3 4 7]

- 1. Applying the PCA method using a graphical representation of clusters in two-dimensional space, the PCA method reduces the number of features to two components since such data reduction may somewhat fix the results.
- 2. Obtaining a PCA data array results in [20 rows x 35 columns]
- The resulting array of PCA data division into six clusters is [3 3 1 1 0 3 2 5 1 1 3 3 3 3 4 1 3 0 3 3 1 3 3 3 1 3 5 3 3 3 3 3 4 2 3], and [6 6 6 7 3 0 4 2 6 7 6 0 5 0 1 0 0 3 8 5 7 6 6 6 7 6 2 5 0 5 5 5 1 4 5] for nine clusters where the number of clusters is the highest value in the array plus one since the clusters start from zero.
- After applying PCA data reduction, these arrays can be graphically represented in the 2D graphs shown in Figures 3.11 and 3.12.

The plot of dividing indicators into six clusters (Source: created by the author) is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Figure 3.11. Similarly, the plot of dividing indicators into nine clusters (Source: created by the author) is available in the same link, Figure 3.12.

As described in Table 3.4, the clustered indicators are listed with descriptions from the metadata received from the World Bank and were used to find a general relation.

The metadata of each extracted indicator from the World Bank's databank described each indicator comprehensively by providing the following data:

1. Code
2. License type
3. Indicator name
4. Long definition
5. Source
6. Topic
7. Periodicity

8. Base period
9. Aggregation method
10. Statistical concept and methodology
11. Development reference
12. Limitations and exceptions
13. General comments
14. License URL

*Refer to https://zenodo.org/records/15570821 file # 3, for comprehensive metadata of the indicators (Chehabeddine, Tvaronavičienė & Zinkevic, 2023).

Some of the remaining indicators do not have complete descriptions in all fields in the metadata tab. Moreover, there is one indicator extracted from the World Bank, but its data availability is rare; in addition, another indicator is not found in the World Bank but extracted from UNEP, UN-Water, and IUCN; therefore, it is preferable to exclude the following two indicators:

1. Droughts, floods, and extreme temperatures (% of the population, average 1990–2009), are available in the databank.
2. 6.6.1 Change in the extent of water related to ecosystems over time, available in UNEP, UN-Water, and IUCN.
   – The amount of water- and sanitation-related official development assistance is part of a government-coordinated spending plan.
   – Proportion of local administrative units that implemented and executed policies and procedures to involve local communities in the management of water and sanitation.

3.3. Critical Security Indicators within the Clusters

It is crucial to find the critical indicators within clusters that guide getting the main cluster that controls the security and resilience of regions. Therefore, it is required to study the relationships between the clusters as shown in the next sub-chapter.

3.3.1. Nexus Between Green Infrastructure and Human Health

Some studies link the advantages of green infrastructure to health (Suppakittpaisarn et al., 2017). However, others have brought up issues related to poor study quality and significant levels of heterogeneity (Twohig-Bennett & Jones, 2018).

The benefits of green infrastructure may include a decline in cardiovascular disease, stroke, diabetes, and total mortality despite not necessarily asserting a direct cause-and-effect relationship (Gascon et al., 2016). Further comment on circulatory disease (Mitchell et al., 2011), obesity (Sanders et al., 2015), respiratory disease morbidity, such as asthma and other atopic disorders (Lambert et al., 2017), and increased senior adults' longevity (Takano et al., 2002), pain control (Han et al., 2016), and immune function (Hartig et al., 2014).

This awareness is growing as its consequences on air pollution and human health are better understood. However, few facts show a connection between green infrastructure projects and measurable health advantages (e.g., reduced mortality, hospital admissions, life years, and mental disorders) (Tiwari et al., 2019).

The research goes beyond the discussion since the authors attempt to integrate the listed and other indicators into one set with different weights, allowing the tool to manage countries' resulting positions in their ecological security performance.

3.3.2. Cluster Categorisation

Cluster 1 can be considered green infrastructure, and Cluster 2 can be regarded as human health for the following reasons.

A study of Cluster 1 indicators shows the following:

1. Access to clean fuels, electricity, and technologies; renewable electricity output; renewable energy consumption; and energy intensity reduction help improve green energy.
2. Increases in forest areas, terrestrial and marine protected areas, and reductions in CO2 emissions and PM2.5 air pollution help improve the green environment.
3. Increasing people's use of at least basic drinking and sanitation water services and renewable energy sources, natural resources, and energy innovation enhances environmental quality.
4. Increasing renewable energy sources reduces CO2 emissions (Balsalobre-Lorente et al., 2018). The usage of renewable electricity and economic growth interact. Regulations for renewable energy are necessary to increase renewable sources and encourage energy innovation, which will lessen the impact of energy and fossil fuels on environmental degradation(Balsalobre-Lorente et al., 2018).

Cluster 2 embraces indicators of people practising open defecation, which is related to maintaining health. This indicator is embedded in Cluster 1, which contains the following indicators: people using at least basic sanitation services, people using at least basic sanitation services, and people using at least basic drinking water services.

Due to their similar content, Clusters 1 and 2 can be combined into one main Cluster (A), green infrastructure and human health.

Cluster 3 can be considered economic rents damaging sustainable growth, and Cluster 6 can be regarded as economic rents that threaten natural resources for the following reasons.

Cluster 3 indicators analysis shows ecological degradation caused by natural resource use according to the following indicators:

1. Annual freshwater withdrawals and the level of water stress are related to water governance.
2. Oil and total natural resource rents are related to environmental protection.
3. Economic rents, used for green management and to impact economic growth, reflect the benefit resulting from the harm that the exploitation of natural resources has caused.

Economic rents received from non-renewables negatively affect ecological security. Cluster 6 indicators analysis shows that economic rent threatens natural resources. Multiple studies have investigated the impacts of economic factors and complexity on the rents from natural resources.

From 2002 to 2017, a sample of 90 economies from around the world, 27 low and lower-middle-income economies (LMEs), 22 upper-middle-income economies (UMEs), and 41 high-income-economies (HIEs), were divided into three subsamples (Canh et al., 2020). The authors showed that reduced threats to natural resources are related to coal, forest, and mineral rents.

Therefore, Clusters 3 and 6 can be combined into one Cluster (B), economic rents from non-renewables.

Cluster 4 can be considered the health of aquacultures, and Cluster 5 can be regarded as a transportation threat for the following reasons.

Cluster 4 indicators analysis shows the aquaculture and total fisheries production related to aquatic life:

1. The negative environmental impacts of the ports and water transportation on the aquatic ecosystem; most industrial and economic activities profoundly impact wildlife (Selamoglu, 2021).
2. Diverse environmental effects brought on by human activities in the water or on land affect aquatic ecosystems (Selamoglu, 2021). Ecological deterioration in oceans worldwide is caused by ship-generated.
3. Trash waste.

Cluster 5 indicators analysis shows that **air transportation threats affect economic growth and aquatic lives** as follows:

- Air transport passengers carry CO_2 emissions related to air transportation, which threaten birds, fish, mammals, and plant species.

Examples of transportation infrastructure where aviation events result in the construction of geotechnical systems are provided through an investigation of geotechnical systems produced in anthropogenic emergency zones during aviation events (Nikolaykin et al., 2023).

A hierarchy of ecological extreme zone levels is offered to the developing systems levels to analyse the environmental impact of aviation incidents. It also supports the idea that increasing flight safety is the best and most practical way to lessen air travel's environmental impact (Nikolaykin et al., 2023).

Green transportation can reduce pollution and promote sustainable aquatic life that benefits fish health.

Therefore, Clusters 4 and 5 can be combined into one "pollution impacts on lives", Main Cluster C.

As commented on cluster characteristics and their indicator interrelationships, Cluster 1 embraced Cluster 2 indicators. The clusters merged into Cluster A, "green infrastructure". Clusters 3 and 6 indicators have similar interrelationships and can be merged into Cluster B, "economic rents". Cluster 4 and Cluster 5 were integrated into Cluster C, "transportation threats". The summary is provided below, in Table 3.6.

Table 3.6. Cluster summary (created by the author)

Clusters Summary		
Main Cluster	**General Aspects**	**Merging Clusters**
A	Green infrastructure	C1 & C2
B	Economic rents as ecological threats	C3 & C6
C	Pollution impacts on lives	C4 & C5

3.3.3. Main Cluster

It is found that Cluster A is the main cluster among the other two clusters (B and C) for the following arguments.

Green infrastructure plays a crucial role in reducing pollution by enhancing natural processes for filtering air and water, thus improving environmental quality, represented by the main cluster "A". This pollution reduction can lead to improved public health and lower healthcare costs, potentially increasing economic rents that control and positively impact clusters "B" and "C".

By lowering pollution levels, green infrastructure can enhance public health, reduce healthcare costs, and increase property values. Consequently, these improvements can attract businesses and residents, further boosting economic growth and economic rents.

Additionally, green infrastructure can enhance property values and attract businesses seeking sustainable environments, thus contributing to economic growth and increased economic rents.

Around the world, many initiatives have attempted to mitigate the effects of anthropogenic air pollution. A detailed investigation of the relationships between air pollution, green infrastructure, and human health would help decision-makers quickly and intelligently choose how to use and manage green infrastructure in urban environments. Social, economic, and environmental benefits can be obtained via green infrastructure.

The relationship between green infrastructure, air quality, and human health suggests that using it strategically could reduce pollutant exposure downwind (Kumar et al., 2019). Significant efforts must be made in decarbonisation and climate change mitigation to provide services to these metropolitan centres that are constantly expanding. It is anticipated that air pollution will be a problem in the developed environment for decades to come in particular (Landrigan et al., 2018). It is projected explicitly that air pollution in the built environment will be a problem for decades to come (Heal et al., 2012; Kumar et al., 2015). The relationship between air pollutants and green infrastructure design (such as species choice and spatial positioning) can benefit or negatively impact individual exposure and human health (Abhijith et al., 2017).

The relationship between green infrastructure, pollution, and economic rents is often discussed in academic and policy literature. A collective understanding derived from numerous studies and sources, referring to sources such as:

- European Environment Agency (EEA) reports on green infrastructure.
- U.S. Environmental Protection Agency (EPA) publications on green infrastructure.
- Various peer-reviewed articles in environmental economics and urban planning journals.

The result is the system of indicators, which comprises 15 critical indicators obtained from the main cluster “A”, which is related to “green infrastructure, health, and pollution”, listed in Table 21 below.

The “15 indicators” system will be studied under four groups/aspects of sustainability to construct a novel ecological security management tool.

The indicators related to the main cluster A are 15 and categorised into four aspects of ecological security, as shown in Table 3.7. The World Bank provided a long (extended) definition for these indicators in the data availability statement to be used as a reference. The experts from different countries, some of whom worked for the World Bank, clearly explained how and what to rank.

Table 3.7. System of 15 indicators related to securing the RD from ecological threats (Source: created by the author)

#	Aspect	Main cluster A	Main Cluster A, Indicator Name (15 Indicators)				
1	Green infrastructure	13,14, 15	Access to clean fuels and technologies for cooking (% of the population)	Renewable electricity output (% of total electricity output)	Renewable energy consumption (% of total final energy consumption)		
2	Sustainable economic growth	10,23	Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal)	Adjusted net savings, excluding particulate emission damage (% of GNI)			
3	Human Health	1,2,3, 5,9	People using at least basic drinking water services (% of the population)	People practising open defecation (% of the population)	People using at least basic sanitation services (% of the population)	People using safely managed sanitation services (% of the population)	Renewable internal freshwater resources per capita (cubic meters)
4	Pollution	16,19, 22,37, 38	The energy intensity level of primary energy (MJ/USD2011 PPP GDP)	CO2 emissions (kg per PPP USD of GDP)	PM2.5 air pollution, population exposed to levels exceeding the WHO guideline value (% of the total)	Marine protected areas (% of territorial waters)	Forest area (% of land area)

Table 3.7 is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, for better resolution.

3.4. Ecological Security Management Tool Construction

A universal tool to evaluate and rank the security of sustainable development in the G20 countries is necessary.

Multi-criteria analysis (MCA) is used to construct a sustainable development security management tool that measures a country's ecological performance and ultimately ranks countries among them based on new relevant, sustainable development parameters using reliable data from international databases such as databank.org (World Development Indicators, n.d.).

The study is comprehensive and has a broader vision compared with other studies that identify the spatial distribution of ecological security using GSI technology by zoning typical arid regions within the country and performing data mining utilising meteorological elements or land-use data, and the weighting was performed by Entropy or FAHP methods; therefore, these methods are limited by the complexity of topography and geomorphology (Li et al., 2024; Liu et al., 2024).

3.4.1. Scoring Methods

MCA approaches generally employ two steps of numerical analysis on a performance matrix:

– **Normalised scoring**

For each criterion, the projected effects of each alternative are awarded a numerical score on the strength of the preference scale. On the scale, favoured alternatives get a higher score, while less liked ones have a lower value. Scales ranging from 0 to 100 are commonly employed in practice, with 0 representing a real or hypothetical least favoured alternative and 100 representing a real or hypothetical most preferred one. The MCA would then analyse all choices between 0 and 100 (*Multi-Criteria Analysis: A Manual*, n.d.).

The basic linear additive evaluation model can be used whenever the indicators are independent. It shows a well-established record of providing robust and practical support to decision-makers working on various problems and circumstances.

The linear model demonstrates how the values of an option of each of the numerous criteria may be blended into a single overall value. It is performed by multiplying the value score on each criterion by the criterion's weight and then adding all those weighted scores together.

– **Weighting**

Numerical weights are applied to each criterion to calculate the relative values of a change between the top and bottom of the defined scale. The most frequent method for combining criteria scores and relevant weights between criteria is to compute a simple weighted average of scores (*Multi-Criteria Analysis: A Manual,* n.d.).

3.4.2. Multi-criteria Decision Analysis – TOPSIS method

Multi-criteria decision analysis is simply a process of decision-making where criteria can be found. This method is attractive because it uses a well-structured framework to evaluate criteria by setting weights and ranking the indicators to establish the importance of all the indicators in decision-making. MCDA does not necessarily provide the only right solution to the problem. Using the MCDA method, a decision maker would be well-oriented between the different alternatives, leading to the choice between the provided possible solutions.

MCDA could provide the best decision between the possible alternatives, or several preference groups could group the final solution by ranking or classifying them (Cheng et al., 2003). By implementing MCDA methods, the decision-maker would always have the choice of the most suitable solution to the problem. It would gather all the possible outcomes of the alternatives, as represented in Figure 3.13. It represents the MCDA problem's structure, where A=A1, A2,..., Ai,..., An is the set of options, and Q = 1,2,..., j,..., q is the set of criteria. Based on this, MCDA methods help decision-makers understand the possible alternative impacts on the decision. MCDA methods could also differ in such cases as the choice of indicators, weight estimation, and mathematical tools, so it is important to choose the right method before evaluating the alternatives (Dytczak et al., 2008).

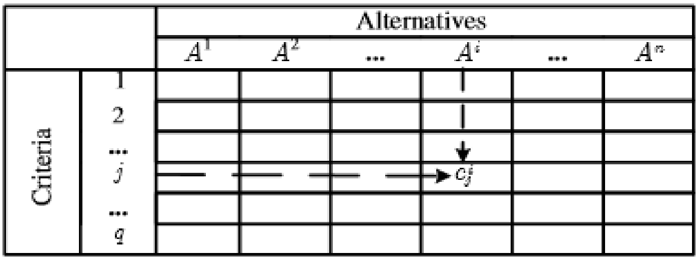


Fig. 3.13. Structure of the MCDA problem (Cheng et al., 2003).

The best methodology for measuring ecological security performance for regions often involves a multi-criteria decision analysis (MCDA) approach, which allows for integrating various indicators and stakeholder preferences. MCDA is indeed applicable, and one suitable method is TOPSIS (technique for order preference by similarity to ideal solution).

TOPSIS belongs to the MCDA group and is one of the most extensively used methodologies in a wide range of scientific fields. The method's main premise is that the best option is the one closest to the greatest solution and farthest away from the worst solution. In other words, the TOPSIS method calculates the shortest geometric distance or the distance to the optimal solution.

The TOPSIS technique necessitates a list of alternatives, normalisation, and weights for each criterion and is widely used in different scientific fields. When comparing TOPSIS with other methods for measuring ecological security in regional development, several factors come into play:

TOPSIS:
Advantages: It provides a clear ranking of alternatives based on their proximity to an ideal solution. It is easy to understand and implement and handles qualitative and quantitative data well.

- **Limitations:** It requires precise data and may be sensitive to criteria weighting.

AHP (analytic hierarchy process):

- **Advantages**: It facilitates complex decision-making by breaking down problems into a hierarchy of sub-problems. It is useful for incorporating expert judgment and stakeholder input.
- **Limitations**: It can be time-consuming and complex, especially with many criteria and alternatives.

Fuzzy logic:

- **Advantages**: It handles uncertainty and imprecision well, making it suitable for ecological assessments where data may be vague or incomplete.
- **Limitations**: It requires expertise in fuzzy set theory and can be computationally intensive.

DEA (data envelopment analysis):

- **Advantages**: It evaluates the efficiency of decision-making units, which is useful for comparing regions based on input-output analysis.
- **Limitations**: It primarily focuses on efficiency rather than overall performance and may not capture all aspects of ecological security.

SAW (simple additive weighting):

- **Advantages**: It is simple, intuitive, and suitable for straightforward problems with well-defined criteria.
- **Limitations**: It is less effective for complex problems with interdependent criteria.

The TOPSIS method is an appropriate method to be utilised for the following reasons:

- **Comprehensive evaluation.** TOPSIS considers multiple criteria, making it ideal for assessing complex ecological security factors.
- **Closeness to ideal solution.** It ranks alternatives based on their distance from an ideal solution, providing clear insights into performance relative to the best possible scenario.
- **Simplicity and clarity.** TOPSIS is straightforward to implement and interpret, making it accessible for decision-makers.
- **Flexibility.** It can accommodate qualitative and quantitative data, allowing for a holistic ecological security assessment.
- **Stakeholder Involvement.** The method can incorporate stakeholder preferences, ensuring that the evaluation aligns with regional priorities and values.

Overall, TOPSIS is well-suited for measuring ecological security due to its balance of simplicity, clarity, and ability to handle multiple criteria, making it a strong choice for regional development assessments and a tool that can be used to evaluate ecological security performance.

The TOPSIS method used data from indicators weighed by experts. All indicators are well-organised and systemised and based on complex evaluation, are represented by the “best” scores or high scores, which show closeness to the right decision, and “bad” scores or low scores, which show the opposite way, which shows the distance to the wrong decision. The TOPSIS method selects the best alternative from a set of alternatives according to several criteria (Hwang & Yoon, 1981).

Let n – be the number of alternatives (countries), m – be the number of criteria (indicators). Set of alternatives $i = 1, \ldots, n$, each of which is evaluated according to several criteria $j = 1, \ldots, m$.

Estimating the best hypothetical solution, represented by V+, and the worst hypothetical solution, represented by V–, requires analysing the data after multiplying the weight by the normalised data. By estimation, the best and the worst hypothetical solutions should consider whether the criterion minimises or maximises.

The best alternative V^+ and the worst alternative V^- were calculated by

$$V+= \{V_1^+, V_2^+, \ldots, V_m^+\} = \{(\max_i \omega_j \tilde{r}_{ij} \,/\, j \in J_1), (\min_i \omega_j \tilde{r}_{ij} / \, j \in J_2)\}, \quad (3.1)$$

$$V^- = \{V_1^-, V_2^-, \ldots, V_m^-\} = \{((\min_i \omega_j \tilde{r}_{ij} / \, j \in J_1), ((\max_i \omega_j \tilde{r}_{ij} \,/\, j \in J_2)\}, \quad (3.2)$$

where J_1 is a set of indices of the maximised criteria, J_2 is a set of indices of the minimised criteria.

The method uses a vector normalisation:

$$\tilde{r}_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{n} r_{ij}^2}} \quad , \tag{3.3}$$

where $\tilde{r}_{ij}$ is the normalised value of the j-th criterion for the *i*-th alternative.

The Euclidean distance to the best and the worst hypothetical solutions is calculated as follows:

The distance D_i^+ of every considered alternative/country to the ideal (best) solutions and its distance D_i^- to the worst solutions were calculated:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} (\omega_j \tilde{r}_{ij} - V_j^+)^2},\ D_i^- = \sqrt{\sum_{j=1}^{m} (\omega_j \tilde{r}_{ij} - V_j^-)^2} \tag{3.4}$$

The criterion $Index_i$ of the method, TOPSIS was calculated by

$$Index_i = \frac{D_i^-}{D_i^+ + D_i^-}, (0 \le Index_i \le 1). \tag{3.5}$$

Two additional hypothetical alternatives (worst and best) were used to calculate a score ranging from 0 to 1. Estimates from this interval are interpreted as percentages. The criteria weights in this study were set by experts with experience in sustainable development indicators, especially from the World Bank; the most important criterion indicator is assigned the most significant weight. The sum of the criteria weights must be equal to 1.

3.4.3. Expert Evaluation

Expert evaluation involves consulting with specialists in the field to assess the validity and reliability of your research methodology, findings, and conclusions. The following steps were considered in how to incorporate expert evaluation:

- **Select Experts**: Identifying and reaching out to experts in ecological security, sustainable development, and related fields.
- **Provide Context**: Sharing research objectives, methodology, and key findings with the experts for their review.
- **Gather Feedback**: Request detailed feedback on the strengths and weaknesses of your approach, as well as suggestions for improvement.
- **Incorporate Insights**: Using the feedback to refine the conclusions, ensuring they are robust and credible.

The following steps were used in preparing the expert evaluation:

- Receiving complete response letters from experts by rating groups of indicators and assigning their rank (the 1st, the 2nd, the 3^{rd,} or the 4th);

- Assign a weight, expressed in per cent of each indicator in a group (e.g., a group green infrastructure "contains three indicators, and the expert can assign 30 per cent for the first, 40 per cent for the second, and 40 per cent for the third, or any other way; the main thing that resulting sum was 100 per cent).

After wrapping up the expert ratings for the 15 targeted indicators in one table, the data indicators of G20 countries were filtered to have only the 15 targeted indicators.

Seven experts from Poland, Lithuania, Italy, South Africa, Germany, Saudi Arabia, and India participated in the evaluation.

All experts have required expertise in the area, which is formally confirmed by high-impact publications in Web of Science and SCOPUS databases and have experience in leading European Union-funded projects in sustainable development or experience working with the World Bank.

After collecting the expert reviews for weighting and ranking indicators from various countries, the following were ordered: 1. Ireland, 2. India, 3. Italy, 4. Poland, 5. Lithuania, 6. Pakistan, 7. Saudi Arabia,

These reviews are gathered in one table for evaluation, as shown in Table 3.8 below.

Table 3.8. Reviews, weighting indicators, and aspect ranking provided by seven experts (created by the author)

#	Groups of Indicators	Security SD Indicators	Experts Location	**Expert Indicators Weighting (%)** **Weighting Each Indicator out of 100% per Aspect and Ranking Each Aspect According to High Importance, 1 Is the Highest**						Average Ranking
				Indicator (13) Weighting (%)		Indicator (14) Weighting (%)		Indicator (15) Weighting (%)		
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	Green infrastructure	13,14,15	1. Ireland	10	(13) Access to clean fuels and technologies for cooking (% of the population)	40	(14) Renewable electricity output (% of total electricity output)	50	(15) Renewable energy consumption (% of the total final energy consumption)	3,3,3, 2,3,1, 4 = MEDIAN (3,3,3,2,3,1) = 3
			2. India	10		30		60		
			3. Italy	10		20		70		
			4. Poland	10		40		50		
			5. Lithuania	10		30		60		

Continued Table 3.8

1	2	3	4	5	6	7	8	9	10	11
			6. Pakistan	35		35		30		
			7. Saudi Arabia	25		25		50		
2	Economic growth	10,23	Experts Location	Indicator (10) Weighting (%)		Indicator (23) Weighting (%)				4,4,4, 4,4,3, 2 = MEDIAN
			1. Ireland	50	(10) Water productivity, total)	50	(23) Adjusted net savings, excluding particulate emission damage (% of GNI)			
			2. India	40		60				
			3. Italy	30		70				
				40		60				
2	Economic growth	10,23	4. Poland	30	(constant 2010 US$ GDP per cubic meter of total freshwater withdrawal	70				(4,4,4,4,3,2) = 4
			5. Lithuania	40		60				
			6. Pakistan	50		50				
			7. Saudi Arabia							

1	2	3	4	5	6	7				8		9		11
3	Human health	1,2,3,5,9	Expert location	Indicator (1) Weighting (%)	Indicator (2) Weighting (%)	Indicator (3) Weighting (%)				Indicator (5) Weighting (%)		Indicator (9) Weighting (%)		2,2,2, 3,2,4, 1 = MEDIAN (2,2,2,3,2,4,1) = 2
			1. Ireland	10	(1) People using at least basic drinking water services (% of the population)	10	(2) People practising open defecation (% of the population)	10	(3) People using at least basic sanitation services (% of the population)	10	(5) People using safely managed sanitation services (% of the population)	60	(9) Renewable internal freshwater resources per capita (cubic meters)	
			2. India	20		10		10		10		50		
			3. Italy	30		10		10		10		40		
			4. Poland	20		10		10		10		50		
			5. Lithuania	10		10		10		10		60		
			6. Pakistan	20		15		18		20		27		
			7. Saudi Arabia	50		0		25		25		0		

End of Table 3.8

1	2	3	4	5	6	7				8		9		10
4	Pollution	16,19,22,37,38	Experts Location	Indicator (16) Weighting	Indicator (19) Weighting	Indicator (22) Weighting				Indicator (37) Weighting		Indicator (38) Weighting		1,1,1, 1,1,2, 3 = MEDIAN (1,1,1,1,1,2,3) = 1
			1. Ireland	5	(16) Energy intensity level of primary energy	65	(19) CO2 emissions (kg per PPP USD)	20	(22) PM2.5 air pollution,	5	(37) Marine protected areas)	5	(38) Forest area (% of	
			2. India	10		50		20		10		10		
			3. Italy	5		35		30		10		20		
4	Pollution	16,19,22,37,38			(MJ/$2011 PPP GDP)		of GDP		population (% of the total)		(% of territorial waters		land area)	Median= 1
			4. Poland	10		50		20		10		10		
			5. Lithuania	10		60		20		5		5		
			6. Pakistan	25		20		23		15		17		
			7. Saudi Arabia	10		10		0		40		40		

*Refer to https://zenodo.org/records/15570821, Table 3.8, for further details (Chehabeddine, Tvaronavičienė & Zinkevic, 2023).

3.4.4. Verification of the Results Using Concordance and χ2

The coefficient of concordance (W) of aspect **green infrastructure,** which contains Indicators 13, 14, and 15, was found to be equal to 0.55, indicating the presence of an average degree of consistency of expert opinions.

The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom K = n-1 = 3-1 = 2 and at the given significance level $\alpha = 0.05$; furthermore, the calculated $\chi 2$ is 7.69 ≥ the tabular value (5.99146), W = 0.55 is not a random value.

Therefore, the obtained results make sense and can be used in further research.

The coefficient of concordance (W) of aspect **economic growth,** which contains Indicators 10 and 23, was found to be equal to 0.71, indicating the high degree of consistency of expert opinions.

The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom K = n-1 = 2-1 = 1 and at the given significance level $\alpha = 0.05$; furthermore, the calculated $\chi 2$ is 5 ≥ tabular (3.84146), W = 0.71 is not a random value.

Therefore, the obtained results make sense and can be used in further research.

The coefficient of concordance (W) of **human health**, which contains indicators 1, 2, 3, 5, and 9, was found to be equal to 0.59, indicating an average degree of consistency in expert opinion**s**.

The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom K = n-1 = 5-1 = 4 and at the given significance level $\alpha = 0.05$; furthermore, $\chi 2$ calculated 16.46 ≥ tabular (9.48773), W = 0.59 is not a random value.

Therefore, the results obtained make sense and can be used in further research.

The coefficient of concordance (W) of **pollution,** which contains Indicators 16, 19, 22, 37, and 38, was found to be equal to 0.39, indicating the presence of a weak degree of consistency of expert opinions.

The calculated $\chi 2$ is compared with the tabular value for the number of degrees of freedom K = n-1 = 5-1 = 4 and at the given significance level $\alpha = 0.05$; furthermore, the calculated $\chi 2$ is 10.91 ≥ the tabular value (9.48773), W = 0.39 is not a random value. Therefore, the obtained results make sense and can be used in further research.

3.4.5. Ecological Security Tool Calculations

The following steps were performed to complete the evaluation:

- Two columns were added to the right table to calculate the max and min. The max has an upward direction, whereas the min has a downward direction. So, for each indicator, there is an indication that these indicators tend to be min or max depending on their desired direction, e.g., going up means (max) and going down means (min), as shown in Table 3.8, as a methodology for calculating alternatives.
- Calculating the mean "Average" for each selected indicator from 2010 to 2019.

The TOPSIS method, created by Hwang and Yoon, 1981, was used to calculate the percentage. Using the TOPSIS method, the best statistical value achieved by a country will become the best alternative, measured by 1. Other values will obtain a value from 0 to 1. The TOPSIS method is used to get the percentages of each indicator obtained for each country, where the indicator data will be used, and experts will provide weights for the indicators.

The programming of this method and the calculation of the results were performed using the **Python** program. The considerations of the hypothetical bad alternative and the hypothetical good alternative are based on the following:

- If the indicator is **maximised**, then its performance is best at the maximum value of the indicator, and the maximum value of this criterion for all countries is considered.

– If the indicator is **minimised**, then its performance is best at the minimum value of the indicator.

Alternatively, contemplating an alternative approach involving the distinct evaluation of Argentina, Indonesia, India, Turkey, South Africa, and the European Union is highlighted in red in the calculation table, available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Table 3.9.

This distinct assessment would account for the absent data while appropriately excluding indicators for unknown values.

It is worth noting how the evaluation for Turkey is calculated. Due to the absence of data for indicator 13, Turkey's effectiveness is calculated based on the two remaining indicators, specifically 14 and 15. It leads to a recalculation of weights: the weights are recalculated as 0.31 / (0.31 + 0.53) and 0.53 / (0.31 + 0.53), resulting in new weight coefficients of 0.37 and 0.63. For Turkey, three data columns are used: evaluations of the worst-case alternative "a", Turkey's evaluation, and the best hypothetical alternative "b".

Based on the proposed indicators, hypothetically, making up the most successful and the worst countries out of the estimates of 20 countries.

If the indicator is maximised, for example, Indicator 13, then the maximum value of this criterion for all countries is taken when forming the best alternative. In the worst-case scenario, the minimum value of the indicator is 13 for all 20 countries.

If the indicator is minimised, then its performance is best at the minimum value of the indicator. Therefore, Indicator 22, for the worst hypothetical country, the value max = 100, and for the best, the value min = 6.263.

Six countries lack data for one indicator, so they cannot calculate their scores for all 15 indicators. However, the remaining 14 countries were evaluated for all 15 indicators using the TOPSIS method. Hypothetically, two countries are added to the list of countries. The percentage core of a hypothetical country, the worst, is rated as 0%, and the best is 100%.

The values of the other six countries were calculated separately, together with hypothetical ones. For each case, the weight values were recalculated (normalised). This distinct assessment would account for the absent data while appropriately excluding indicators for unknown values.

The table of calculation and results of the TOPSIS method in calculating alternatives is available in the Zenodo link https://zenodo.org/records/15570821 file # 3, Table 3.9, for further details.

**Notes*. The value zero "0" represents zero efficiency. For example, in Saudi Arabia, the indicator "People practising open defecation (% of the population)" is "0", which means no implementation of defecation. Regrettably, there is a lack of data for Indicators 13, 5, and 16, necessitating consideration for their removal. Noticeably, the fifth indicator exhibits the most significant data deficiency. However, eliminating these indicators could potentially mar the integrity of the proposed indicator system.

Regarding "#NUM!", it is simply a failure of the country to provide data. The results are for the mean, whereas the median did not improve the estimates of countries with zero values, and they remained there, so it is decided to count the average values. The final combined results were not considered average but over the entire dataset. The weights were recalculated since the sum should equal 1, as shown in Table 3.10.

Table 3.10. Alternative ecological security weighting and direction for each indicator (created by the author)

Indicator #	Indicator Weighting	Groups of Aspects	Alternative Desired Direction min/MAX
13	0.037	Green Infrastructure	MAX
14	0.071		MAX
15	0.121		MAX
Weight of Aspect Green Infrastructure		23%	
10	0.057	Economic growth	MAX
23	0.086		MAX
Weight of Aspect Economic Growth		14%	
1	0.063	Human Health	MAX
2	0.024		Min
3	0.035		MAX
5	0.038		MAX
9	0.111		MAX
Weight of Aspect Human Health		27%	
16	0.039	Pollution	Min
19	0.146		min
22	0.068		min
37	0.05		MAX
38	0.054		MAX
Weight of Aspect Pollution		36%	
Total Weight of Aspects	**1.00**	100%	

The ecological security tool comprises indicator values showing how far they are from the ideal alternative (an ideal alternative is the best value achieved). This tool will allow for managing the ultimate result (ecological security). The method will enable getting a tool similar to an Index.

Refer to the Zenodo link https://zenodo.org/records/15570821 file # 3, Table 9, row 71, for further details on the ecological security tool formula (Chehabeddine et al., 2023).

3.5. Results

The ecological security tool composition and weights of indicators within are crucial for understanding why the presented results are of one kind or another.

After calculating a country's security ecological security tool, compare the results with the following criteria, based on the interpretation of the obtained results, to determine the country's ecological security status.

The instrumental tool will be used to alert insecure countries to mitigate the related threats of this ecological security tool, leading to the development of a secure region.

The decision-makers of each country will decide the mitigation actions depending on each country's rules, regulations, and policies. The application of this tool assists in understanding the weaknesses, which provides solutions that contribute to management science and management theories.

3.5.1. Alternative Results for Group 20 Countries

Tables 3.11 and 3.12 below show the results of the indicator alternatives related to the main cluster A for the G20 group countries. These will assist us in determining the indicators for ranking the countries' ecological security.

Table 3.11. Alternative results for G20 countries (created by the author)

Alternatives (G20 for 4 – Aspects)	Hypothetic Bad Alternative		**1. Saudi Arabia**	**2. Argentina**	**3. Australia**	**4. Brazil**	**5. Canada**	**6. France**	**7. Germany**	**8. Italy**	**9. Japan**	**10. Indonesia**	Hypothetic Good Alternative
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Green infrastructure	%	0.00 %	10.90 %	27.68 %	21.49 %	99.30 %	59.05 %	27.92 %	30.14 %	37.99 %	17.32 %	59.86 %	100%
	Rank		**20**	**11**	**14**	**1**	**4**	**10**	**9**	**5**	**17**	**3**	

End of Table 3.11

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Economic growth	%	0.00 %	45.20 %	11.11 %	24.61 %	25.94 %	19.21 %	29.54 %	45.15 %	15.32 %	18.16 %	28.34 %	100%
	Rank		**3**	**19**	**12**	**11**	**14**	**7**	**4**	**16**	**15**	**10**	
Human health	%	0.00 %	25.74 %	11.21 %	36.85 %	42.11 %	97.67 %	26.78 %	26.43 %	26.93 %	27.10 %	15.30 %	100 %
	Rank		14	19	4	3	1	9	12	7	6	17	
Pollution	%	0.00 %	43.97 %	56.58 %	55.94 %	73.28 %	50.71 %	74.08 %	70.86 %	64.46 %	62.21 %	62.89 %	100 %
	Rank		**17**	**12**	**13**	**2**	**15**	**1**	**3**	**7**	**9**	**8**	
Combined Results			0.3052	0.3141	0.3555	0.6219	0.5967	0.4134	0.4113	0.4003	0.3399	0.4215	1
Security Ecological Security Percentage			30.52 %	31.41 %	35.55 %	62.19 %	59.67 %	41.34 %	41.13 %	40.03 %	33.99 %	42.15 %	100 %
Overall Rank			**19**	**17**	**11**	**1**	**2**	**5**	**6**	**7**	**14**	**4**	

Table 3.12. Combined results and general ranking for G20 countries (created by the author)

Alternatives (G20 for 4 – Aspects)	Hypothetic Bad Alternative		**11. India**	**12. Mexico**	**13. Russian Federation**	**14. South Africa**	**15. Turkey**	**16. United States**	**17. United Kingdom**	**18. Korea, Rep.**	**19. China**	**20. European Union**	Hypothetic Good Alternative
Green infrastructure	%	0.00 %	60.96 %	22.49 %	16.89%	30.63 %	30.79 %	21.17 %	18.72%	11.82 %	27.58 %	36.62%	100%
	Rank		**2**	**13**	**18**	**8**	**7**	**15**	**16**	**19**	**12**	**6**	
Economic growth	%	0.00 %	42.71 %	14.65 %	19.67%	4.73 %	28.36 %	14.58 %	51.24%	44.64 %	50.91 %	28.76%	100%
	Rank		6	17	13	20	9	18	1	5	2	8	
Human health	%	0.00 %	8.76 %	25.74 %	44.60%	13.20 %	26.27 %	29.21 %	26.71%	26.45 %	25.70 %	26.82%	100%
	Rank		**20**	**14**	**2**	**18**	**13**	**5**	**10**	**11**	**16**	**8**	
Pollution	%	0.00 %	48.94 %	62.01 %	35.72%	11.10 %	58.79 %	68.19 %	67.70%	51.15 %	14.32 %	66.24%	100%
	Rank		**16**	**10**	**18**	**20**	**11**	**4**	**5**	**14**	**19**	**6**	
Combined Results			0.3894	0.3438	0.308	0.1833	0.4001	0.3525	0.396	0.3248	0.3142	0.4365	1
Security Ecological Security percentage			38.94 %	34.38 %	30.80%	18.33 %	40.01 %	35.25 %	39.60%	32.48 %	31.42 %	43.65%	100%
Overall Rank			**10**	**13**	**18**	**20**	**8**	**12**	**9**	**15**	**16**	**3**	

*For further details on the tables and figures below, refer to the Zenodo link https://zenodo.org/records/15570821 file # 3, Table 9.

Figure 3.14 shows diagrams graphically comparing the combined results among G20 countries obtained in Tables 3.11 and 3.12.

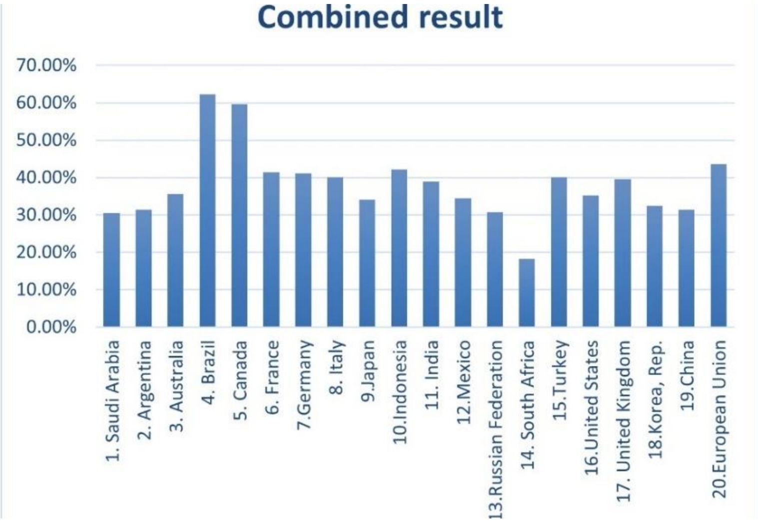


Fig. 3.14. Bar chart representation of the ecological security performance for the combined results of the G20 group (created by the author)

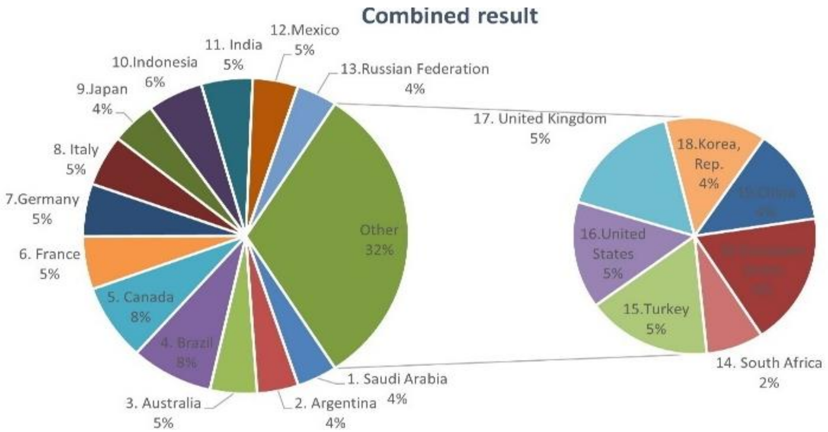


Fig. 3.15. Pie chart representation of the ecological security performance for the combined results of the G20 group (created by the author)

Refer to the Zenodo link https://zenodo.org/records/15570821 file # 3, Table 3.9, for further details and better resolution.

The above two figures show the graphical representation of the ecological security performance of G20 countries represented in the bar chart and the pie chart to compare and rank G20 countries according to their ecological security performance, to categorise them into the groups discussed in the next sub-chapter.

3.5.2. Interpretation of the Results

The results are utilised for identifying gaps in ecological security performance to alert the G20 group, an important global object selection, to manage their ecological security performance and accordingly propose the improvement plan that suits each country's policies, rules, and regulations, in which to enhance sustainable development and consequently securing regional development. The measurement of ecological security in the selected countries has led to exciting results, which will be discussed below.

The ultimate results are presented in Figure 3.14 above; let us divide all considered countries into several bigger groups.

The first group would embrace countries with a relatively best performance. Attributing to these group countries that are remoted from their potential ideal state, or alternative, as called this state in this research context, with around 60 per cent. This group consists of just two countries, which have achieved the following results: Brazil nears the ideal state by 62.19 per cent, and Canada nears the ideal alternative by 59.67 per cent, respectively.

The second conditional group will embrace countries that get into the 45 per cent to 40 per cent interval. In our case, this group would consist of the European Union, Indonesia, France, Germany, Italy, and Turkey, which is somewhat surprising that Turkey falls into the group with 40.01 per cent.

The third group countries, which show comparatively worst performance in the area of ecological security, specifically, being below a benchmark of 40 per cent, are the United Kingdom (has reached only 39.60 per cent of the ideal state), the United States, Australia (with 35.55 per cent), China (with the result in the group of 31.42 per cent), then Korea and Saudi Arabia. In contrast, South Africa appears to be the most ecologically insecure country, with 18.33 per cent.

The reasons that countries fell into one or other groups vary since the result is a composite indicator, which it will further call an "**ecological security management tool**", comprised of selected indicators with different weights.

The ecological security tool is composed of three groups with different weights, comprising 100 per cent.

The indicators inside each aspect group have their weights, too, as indicated in Table 3.11. It is important to emphasise that in the first aspect group, green infrastructure, Indicator 15, "renewable energy consumption (% of the total final energy consumption)" has the most significant weight, e.g., 0.121.

In the second group aspect, "green economic growth", Indicator 23, "adjusted net savings, excluding particulate emission damage (% of GNI)", has a higher weight than the others and is 0.086.

In the third group of aspects, "human health", Indicator 9, "renewable internal freshwater resources per capita (cubic meters)" has an attributed weight of 0.111.

In the fourth-ranked aspect, "pollution", the most important is Indicator 19, "CO2 emissions (kg per PPP USD of GDP)", with a weight of 0.146, the highest among all indicators.

3.5.3. Application of Ecological Security Tool

After reviewing the G20 ranking according to the created tool, South Africa ranked 20, as shown in Table 3.12, and this could be justified because it is a developing country. However, for Saudi Arabia, which ranked 19, as shown in Table 26, it is curious to study the weak points deeply, especially since Saudi Arabia is a middle-developed country, as mentioned in Table 1.10.

Selecting Saudi Arabia to check its Ecological security weakness using the created ecological security tool. It has been found that seven indicators, 9, 10, 14, 15, 22, 37, and 38, highlighted in red in Table 3.13 below, where they have a low score, that guides and directs the country's decision-makers focusing on improving the ecological security status of this country.

Table 3.13. Alternative ecological security indicator status (created by the author)

Aspect	Indicator #	Hypothetic Bad Alternative "a"	Hypothetic Good Alternative "b"	Saudi Arabia's Alternative Status
1	**2**	**3**	**4**	**5**
Green infrastructure	13	5.34693692	100	95%
	14	0.00022274	79.67195066	0%
	15	0.00631855	44.02935298	0%
Weight	23%	**Total Aspect Ecological Security Results**		11%
Economic growth	10	3.4849	327.5693611	9%
	23	1.343603931	26.578	80%
Weight	14%	**Total Aspect Ecological Security Results**		45%
Human health	1	86.8676	100	99%
	2	93.7726	0	0%
	3	50.4806	100	99%
	5	41.8555	98.7784	41%
	9	77.4119	80042.1656	0%

End of Table 3.13

1	2	3	4	5
Weight	27%	**Total Aspect Ecological Security Results**		26%
Pollution	16	9.096	3.208	50%
	19	0.636	0.121	50%
	22	100	6.263	0%
	37	0.106	45.357	4%
	38	0.454	68.447	0%
Weight	36%	**Total Aspect Ecological Security Results**		44%

The weakness indicators for Saudi Arabia are the following indicator numbers (9, 10, 14, 15, 22, 37, and 38), which are highlighted in red in Table 3.13 above.

It is concluded that measuring a country's ecological security management tool to be used for controlling its weaknesses leads to managing its sustainable development aspects.

As shown in the above example of Saudi Arabia, Indicator 14, renewable electricity output, and Indicator 15, renewable energy consumption, have shallow scores highlighted in red that require attention to improve in order to enhance the green infrastructure (one of the sustainability facets) in Saudi Arabia.

Similarly, for the other sustainability aspects, improving indicator scores in economic growth, human health, and pollution will improve each country's ecological security. Consequently, it will specifically promote the country to a higher ecological security level, and this improvement will generally be reflected in the countries of the same cluster, thereby improving the ecological security of all G20 countries.

The areas of application for the security tool

– 1. **Regional planning and development.** Infrastructure development, such as analysing transportation, utilities, and other infrastructure supporting regional sustainable development.

– 2. **Environmental management.** Integrating security aspects in developing an ecological security tool that can adequately manage resources such as water, forests, and minerals, as well as control pollution to monitor and reduce environmental impacts.

– 3. **Public health.** Analysing the distribution of healthcare facilities and services to ensure equitable access for all residents and epidemiological modelling by using data to predict and manage public health crises, such as disease outbreaks.

It is recommended that the ecological security tool be examined in different aspects for each country of the G20 group to prepare a suitable mitigation plan that suits each country.

The policies for enhancing low ecological security indicator scores

The process for improving the scores of any indicators should follow each country's rules and regulations. Samples of policy approaches that can be used to improve the low scores of ecological security indicators in various domains, tailored to different sectors, along with examples, are listed below.

These policies can be adapted and tailored to specific countries and contexts based on the challenges faced. Engaging stakeholders, including community members, experts, and policymakers, is crucial in designing effective interventions that can lead to sustainable improvements in the low indicator scores.

1. Health

• **Policy:** Expanded access to healthcare services.
• **Example:** Increase funding for community health clinics in underserved areas to provide affordable healthcare services.
• **Policy:** public health campaigns.
• **Example**: Launch campaigns to raise awareness about preventive health. Measures, such as vaccinations and healthy lifestyle choices.
• **Policy:** Mental health support programmes.
• **Example:** Develop community-based mental health services to address rising mental health issues among youth and adults.

2. Environmental sustainability

• **Policy:** Renewable energy incentives.
• **Example:** Offer tax credits or subsidies for homeowners and businesses that install solar panels or other renewable energy systems.
• **Policy:** Conservation programmes.
• **Example:** Implement initiatives that promote conservation practices among farmers and landowners to protect natural resources.
• **Policy:** Urban green spaces.
• **Example:** Develop parks and green spaces in urban areas to improve air quality, enhance biodiversity, and provide recreational opportunities.

3.5.4. Contribution to Management Science

The intersection of security and sustainability is increasingly recognised in management science. Security considerations are essential for addressing ecological threats, resource scarcity, and climate change, which can lead to social unrest and conflict.

The contributions of the dissertation were in management science, as follows:

- The dissertation's contribution to management science at the macro level is multifaceted, influencing economic stability, public policy, crisis management, and international relations.
- By integrating security principles into management practices, organisations and governments can enhance resilience, promote sustainable development, and create a safer environment for individuals and communities.
- The optimised PSR framework that considers ecological threats contributes to creating the security model, which optimises the existing sustainable development models to embrace the security aspects, contributing to management science.
- The created security model, measurement tool, and methodology contributed to the management science in integrating security principles to sustainable development to mitigate the ecological threats facing the G20 group, in which regional planners and policymakers can foster secure sustainable development, improve quality of life, and enhance economic resilience for regions.
- Collaboration among stakeholders, including government agencies and international organisations, is needed to create comprehensive security strategies that shape public policy and governance structures to secure regional sustainable development, contributing to management science. Accordingly, formulating policies for enhancing ecological security according to each country's rules and regulations will affect regional sustainable development, contributing to management science.

The security tool utilised statistical methods, such as MCDA-TPOSIS, to analyse data, which evaluates different alternatives based on their potential outcomes, contributing to management science.

- Global innovativeness in research and development in the G20 involves several key strategies:
  - **Technological advancements:** Investing in clean energy, sustainable agriculture, and smart city technologies to reduce ecological impact.
  - **Advanced technologies**: Developing and implementing technologies such as renewable energy, smart grids, and carbon capture to mitigate ecological threats.
  - **International collaboration:** G20 nations working together on joint research projects to tackle shared environmental challenges.

- **Collaborative research:** G20 countries collaborate on research initiatives to address global ecological challenges, sharing knowledge and resources.
- **Policy frameworks:** Developing policies integrating security and sustainability, ensuring resilience against ecological threats.
- **Policy innovation:** Creating and adopting policies that promote sustainable practices and integrate security measures to protect against ecological risks.
- **Policy support:** Government policies and incentives can encourage innovation by providing funding, infrastructure, and a supportive regulatory environment.

Examples of practical applicability

- **Urban development projects:** Cities using management science techniques plan smart growth initiatives that balance economic development with environmental sustainability.
- **Regional transportation authorities:** Employing optimisation models to enhance public transportation systems and reduce travel times.
- **Disaster response planning:** Using simulation models to prepare for natural disasters, ensuring effective resource distribution and emergency response.

3.5.5. Contribution of the Dissertation to Management Theories

The contributions of the dissertation results were in management theories, as follows:

1. Securing regional development is a dynamic field that continues to evolve as new challenges and opportunities arise, so policymakers and planners can draw on these theories to design interventions that promote sustainable development, involving security for sustainable development in various regions around the world.
2. The dissertation’s findings contributed to the regional development theory by integrating security principles into regional development by measuring regional ecological security instead of only addressing the worsening of the global environment.
3. Compared with the conventional study of regional development theory, which emphasised the coordination of the relationship among population,

resources, environment, and development, the dissertation emphasised integrating security principles into SDGs in measuring regional sustainable development, which stresses the complexity and wholeness of the sustainable development process.

4. The dissertation's findings contributed to the systems theory at the macro level by considering the impact of one indicator affecting sustainability and the country's ecological security. The accomplished Systems theory can have practical implications on regional development and the development of countries or country groups.

The contributions of scientific novelty to the management theories that scientific novelty can enhance management theories in several ways, such as:

- **Enhancing adaptability:** Insights into ecological threats can help management theories adapt to changing environments and emerging challenges.
- **Improving sustainability:** The security approaches can incorporate sustainability into management practices, aligning them with contemporary ecological and social goals.

Specifically, the following management theories have been improved to address contemporary challenges and improve effectiveness:

1. **Systems theory** emphasises the importance of understanding the whole system. It was improved in managing ecological systems and providing deeper insights into sustainability and security.
2. **Regional development theory** explores the economic growth and development of specific geographic areas, helping policymakers and planners understand the dynamics of regional development and design strategies to promote balanced growth. It has been improved in several ways, such as:
   - **Sustainable development:** Integrating security principles with sustainable development for sustainable regional growth.
   - **Resilience and adaptation:** Contributions from climate science can inform strategies to build resilient regions in the face of environmental changes.

The ecological security model can enhance management theories in several ways, such as:

- **Integrating environmental considerations:** It incorporates security against ecological threats into management decisions, ensuring that ecological impacts are considered alongside economic and social factors.

- **Promoting sustainable practices:** By focusing on ecological security, management theories can prioritise security and sustainability, leading to long-term resilience and resource efficiency.
- **Driving innovation:** The focus on ecological security can stimulate innovation in processes and technologies that reduce the impact of ecological threats to enhance sustainability and regional development.

The ecological security tool can enhance management theories in several ways, such as:

- **Strategic planning:** Supports long-term planning by highlighting ecological trends and potential future challenges.
- **Enhanced accountability:** Encourages transparency and accountability by tracking ecological impacts and improvements over time.

3.6. Conclusions of the Third Chapter

The following conclusions are based on the results:

1. The ecological security tool is an instrumental tool that promotes each country's ecological security and contributes to regional sustainable development theory, which emphasises the relationship among population, resources, environment, and development.
2. The created ecological security tool measures and ranks G20 country's ecological security and then categorises G20 countries into three main groups to alert the insecure countries to be secured against ecological threats by enhancing low scores of the related sustainability aspects and security development indicators, leading to a secure region development, and consequently the cluster of countries, following the systems (cluster) theory, that states the impact of one indicator affecting the whole sustainable development system.
3. A system of 15 security SD indicators and their data is found clustered in one main cluster out of 1443 indicators available in the World Bank's database that controls the ecological security of G20 regions.
4. Indicator clustering assists in focusing on critical indicators in the main cluster.
5. The suitable method utilised was MCDA-TOPSIS, whereas the evaluations were via seven experts around the world, and the verifications of results using Concordance and $\chi 2$.

6. The ecological security tool was created to appropriately weigh these indicators using experts' evaluation to measure and rank the country's ecological security. It will assist in providing the proper solution to promote ecological security according to each country's policies, rules, and regulations.
7. The dissertation's findings contributed to the regional sustainable development theory by integrating security principles into regional sustainable development by measuring regional ecological security instead of only addressing the worsening of the global environment.
8. The dissertation's findings contributed to the Systems theory at the macro level by considering the impact of one indicator affecting sustainability, then on the country's ecological security, and then on the cluster of countries, consequently affecting the regional sustainable development of the G20 group.
9. The result is subject to some uncertainties and qualifications where knowledge gaps and measurement issues cause uncertainty, such as measurement error, missing data, and restoring data indicators from the World Bank's database.
10. Some indicators were removed because their data were missing by more than 75%, while I recovered indicators whose data were missing by less than 25%.
11. The collection of indicators is limited to selecting ecological indicators threatening SD goals provided in the World Bank's sustainability database.

General Conclusions

1. The analysis of scientific literature revealed various approaches to sustainability and security. By integrating security aspects into sustainable development, organizations and governments can strengthen the resilience of countries to various threats. When planning sustainable regional development, it is very important to assess ecological insecurity and formulate regional development goals according to the characteristics of the region, focusing on the natural environment. The principles of security are integrated into the developed regional development model, thus taking into account the impact of modern ecological threats on the development of countries. This approach allows us to supplement the principles of sustainable development and construct a tool for measuring ecological security.
2. The multi-criteria decision-making method TOPSIS was chosen because it allows for a clear ranking of alternatives according to their proximity to the ideal solution. It is easy to understand and implement, it handles qualitative and quantitative data well, and due to its simplicity, clarity, and ability to handle multiple criteria balances, it is well-suited for assessing ecological security, making this method a good choice for assessing regional development. The result provides a tool that can be used to assess the state of ecological security of countries.

3. The wide range of threats that many countries face requires a new approach to regional development. Until now, regional development has mostly been associated with the tasks of sustainable development. Traditionally, there has been a discussion of how to assess the sustainability of development. This dissertation poses the question differently: it proposes integrating security aspects into the goals of sustainable development. Security is a broad concept. The dissertation discusses the types of insecurity and groups the threats that determine them. The classic threat of armed conflict and war is only mentioned, it is not analyzed in more detail. The dissertation focuses on ecological threats. A model of sustainable and safe regional development is constructed. On its basis, a tool is created that allows assessing the development of G20 countries, focusing on ecological threats. The tool is created based on a grounded indicator system consisting of 15 indicators and using the multi-criteria method TOPSIS.The developed tool measures and ranks the ecological security of a country, which allows this tool to be used to manage the sustainable and safe development of the G20 countries, whose data were used in the work.
4. The scientific novelty of the dissertation is related to the developed model and tool. The author formulates the defence statements and describes the contribution of the results to management science.

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Summary in Lithuanian

Įvadas

Problemos formulavimas

Naujųjų technologijų, globalizacijos bei klimato kaitos kontekste pasaulis susiduria su šiuolaikinėmis grėsmėmis, kurios trukdo tvariai ir saugiai regioninei plėtrai. Būtina mažinti taršą, kad būtų išlaikyta „žalioji“ aplinka ir ekologinės grėsmės nekeltų pavojaus tvariai, dar vadinama darnia, regioninei plėtrai.

Pasaulinė darni plėtra be pridėtinės vertės kūrimo, turi siekti į ekonominį vystymąsi integruoti saugumo principus, pagal kuriuos įvertinamas šiuolaikinių grėsmių spektras tam, kad būtų užtikrintas saugumo ir 17 darnaus vystymosi tikslų (DVT) tarpusavio ryšys.

Tvarios plėtros principai turėtų apimti tiek darnaus vystymosi tikslus (DVT), tiek saugumą. Ligi šiol diskutuojama, koks modelis galėtų atspindėti ekologinių grėsmių poveikį regionų darnaus vystymosi tikslų (DVT) įgyvendinimui.

Darbo aktualumas

Vieningai sutariama, kad tvarios plėtros skatinimas – tai būdas užtikrinti klestinčią šalių, regionų ir mūsų planetos ateitį (Foroudi et al., 2024). Tinkamas regioninės plėtros valdymas reikalauja turėti patikimą ekologinio saugumo matavimo įrankį, sukurtą remiantis tvarios ir saugios regioninės plėtros modeliu. Ši priemonė užtikrins susijusių darnaus vystymosi tikslų (DVT) apsaugojimą nuo ekologinių grėsmių, o tai lems tvarią ir saugią regioninę plėtrą. „*Web of Science*“ duomenų bazėje galima rasti 459 mokslinius straipsnius, susijusius su tema „Ekologinis saugumas ir tvari regioninė plėtra“. Nustatyta, kad 331 iš 459 mokslinių tyrimų (apie 72 % visų tyrimų) buvo atlikti per pastaruosius penkerius metus, t. y. laikotarpiu nuo 2020 iki 2025 m. 2024 m. su šia tema buvo susijęs 81 tokio tipo straipsnis. Tai rodo šios temos svarbą pastaraisiais metais.

Tyrimo objektas

Tyrimo objektas – tvari ir ekologiškai saugi regioninė plėtra, o tyrimo problema yra orientuota į jos sprendimą.

Darbo tikslas

Disertacijos tikslas – sukurti naują tvarios ir saugios regioninės plėtros modelį ir priemonę G20 šalių ekologinio saugumo rodikliams įvertinti, kurie galėtų būti naudojami šių šalių vystymuisi valdyti.

Darbo uždaviniai

Siekiant disertacijos tikslo, buvo suformuluoti tokie uždaviniai:

1. Teoriškai pagrįsti regioninės plėtros saugumo ir darnaus vystymosi tikslų (DVT) saugumo aspektų sąsajas.
2. Išryškinti regioninės tvarios plėtros nesaugumo aspektus, kuriuos būtina išsamiau išnagrinėti, sutelkiant dėmesį į ekologines grėsmes.
3. Sukurti tvarios ir ekologiškai saugios regioninės plėtros modelį, pagrįstą darnaus vystymosi tikslų (DVT) ekologinio saugumo aspektais.
4. Pasiūlyti argumentus, leidžiančius pagrįsti ekologinio saugumo rodiklių sistemą, kuri bus naudojama regioninei plėtrai valdyti siekiant ją apsaugoti nuo ekologinių grėsmių.
5. Sukurti naują valdymo priemonę, susijusią su sukurtu saugumo modeliu, kuri matuoja, vertina ir reitinguoja tvaraus vystymosi saugumo lygius ekologinių grėsmių kontekste bei leidžia užtikrinti tvarią ir saugią G20 šalių regioninę plėtrą.

Tyrimo metodika

Tyrimo objektui tirti buvo panaudota toliau aprašyta prieiga ir tyrimo metodai. Darnaus vystymosi tikslų (DVT) ekologinio saugumo rodikliai parinkti bei statistiniai duomenys G20 šalims gaunami iš DVT duomenų bazės, kurią pateikia Pasaulio bankas. Tyrime derinami kiekybiniai ir kokybiniai metodai. Taikomas šalių ir rodiklių grupavimas bei pagrindinių komponentų analizės (PCA) metodas.

Remiantis šia metodologine prieiga buvo sugrupuoti 43 saugumo rodikliai taikant K-vidurkių metodą. Atlikus gautų rezultatų analizę, buvo pasiūlyta rodiklių sistema, susidedanti iš 15 svarbiausių rodiklių, darančių įtaką visų G20 šalių ekologiniam saugumui. Sudarius teoriškai pagrįstą rodiklių sistemą, buvo kreiptasi į ekspertus, kurie įvertino atrinktus rodiklius.

Rezultatai ir hipotezės buvo analizuojami taikant daugiakriterį sprendimų priėmimo metodą TOPSIS, kuris iš alternatyvų rinkinio parenka geriausią alternatyvą, kad įvertintų kiekvienos šalies ekologinio saugumo rodiklius ir reitinguotų G20 šalių ekologinio saugumo aspektus. Skaičiavimai buvo atlikti naudojant „Python“ programą, o rezultatai patikrinti naudojant konkordanciją ir $\chi 2$ kriterijų.

Disertacijoje išskiriami tokie *tyrimo etapai*:

1. Modelio, pagrįsto ekologinio saugumo principų integravimu į tvarią regioninę plėtrą, sukūrimas.
2. Ekologinio saugumo rodiklių identifikavimas naudojant sukurtą tvarios ir saugios regioninės plėtros modelį.
3. Darnaus vystymosi tikslų (DVT) saugumo rodiklių duomenų rinkimas iš Pasaulio banko duomenų bazės.
4. Ekologinio saugumo rodiklių klasterizavimas taikant K-vidurkių metodą.
5. Kiekvienos grupės (klasterio) charakteristikų analizė ir grupavimas, siekiant suformuoti rodiklių sistemą.
6. Septynių ekspertų atliekamas gautos rodiklių sistemos rodiklių įvertinimas ir jų reitingavimas pagal keturis aspektus.
7. G20 grupės šalių reitingavimas, naudojant sukurtą ekologinio saugumo matavimo priemonę.
8. Rezultatų patikimumui patikrinti buvo taikomas konkordancijos koeficiento principas.
9. Gautų rezultatų analizė pagal šalių veiklos rezultatus.
10. Sukurtos ekologinės saugumo priemonės G20 šalyse narėse panaudojimo rezultatų įvertinimas, siekiant išsiaiškinti tvarios ir saugios plėtros valdymo trūkumus bei pasiūlyti galimus sprendimo būdus tokiems trūkumams sumažinti.
11. Gauti rezultatai aprobuoti pasitelkus atvejo analizės metodą (iš G20 šalių buvo pasirinkta Saudo Arabija).

Darbo mokslinis naujumas

Tyrimo naujumas yra tas, kad buvo sukurtas tvarios ir saugios regioninės plėtros modelis, kuriame atsižvelgiama į ekologinio saugumo grėsmes, bei nustatomi su jomis susiję atitinkamų darnaus vystymosi tikslų (DVT) saugumo aspektai.

Atlikus esamų tyrimų analizę paaiškėjo, kad dar nėra sukurtas priimtinas regioninio ekologinio saugumo nustatymo įrankis. Disertacijoje pasiūloma priemonė, kuri būtų naudinga valdant tvarią ir ekologiškai saugią regionų plėtrą.

Tyrimo naujumas atsiskleidžia per konkrečius aspektus:

- Sukurtas naujas tvarios ir ekologiškai saugios regioninės plėtros modelis, leidžiantis įvertinanti kylančias ekologines grėsmes.
- Pasiūlytas įrankis, kuris gali būti praktiškai naudingas G20 šalims valdyti tvarią regioninę plėtrą atsižvelgiant į kylančias ekologines grėsmes.

Tyrimo originalumas yra ekologinėms grėsmėms įvertinti pasirinkta rodiklių sistema ir tos rodiklių sistemos integravimas į regioninę tvarią plėtrą (detaliau žr. 1.7 poskyrį „Regioninės grėsmės“).

Ši disertacija prisidėjo prie vadybos mokslo vystymo papildant Sistemų bei Regioninio vystymo teorijų formuluotes, nurodant, kad turi būti įvertinamos šiuolaikinės išmatuojamos ekologinės grėsmės numatant sistemų, įjungiančių regionus, vystymosi ypatybes.

Darbo rezultatų praktinė reikšmė

Disertacijos rezultatai turi tokių svarbių praktinių reikšmių:

- Pasiūlytas modelis leidžia praktikams (politikams, politikos formuotojams, institucijoms ir vyriausybei) geriau suprasti regioninės plėtros vystymo valdymo tikslus bei būdus.
- Sukurta ekologinio saugumo rodiklių sistema nustato sritis, kurios padėtų aptikti tvarios ir saugios regioninės plėtros spragas, tai leistų vyriausybei priimti veiksmingus politinius sprendimus dėl regioninės plėtros ir skatintų silpnųjų regioninės plėtros sistemos dalių tobulinimą.
- Sukurta priemonė padėtų parengti naujus vyriausybės išleidžiamus tvarios ir saugios regioninės plėtros įgyvendinimo reglamentus.

Ginamieji teiginiai

Toliau pateikiami teiginiai, pagrįsti šio tyrimo rezultatais, kurie gali būti disertacijos ginamaisiais teiginiais:

1. Pasiūlytas tvarios ir saugios regioninės plėtros modelis, įvertinantis išmatuojamas ekologines grėsmes, galės būti naudingas G20 šalių vystymosi valdymo procese pagerins vadybos mokslo žinias ir galėtų būti taikomas būsimiems vadybos tyrimams.
2. Tyrime įvardinami tvarios plėtros ekologinio saugumo įgyvendinimo regioninėje plėtroje iššūkiai ir spragos, tokios kaip pasitikėjimo taršos valdymu stoka ir nepasirengimas įgyvendinti ekologinių grėsmių neutralizavimą.
3. Regioninės plėtros modelis turi būti išplėstas, siekiant užtikrinti saugumą nuo nustatytų šiuolaikinių ekologinių grėsmių, suskirstytų į gresiančias, naujas, tebesitęsiančias ir atsinaujinusias grėsmes kurios galėtų būti sukurtos iš kitų grėsmių kategorijų, ir suformuluoti saugumo rodiklių sistemą, pagal kurią būtų galima vertinti šalių veiklą pagal ekologinio saugumo modelį.
4. Sistemų bei Regioninės plėtros teorijos gali būti išplėstos, jas papildant teiginiu, jog turi būti įvertintos šiuolaikinės išmatuojamos ekologinės grėsmės numatant veiksnius, darančius įtaką sistemų, tarp jų ir regionų, funkcionalumui.
5. Ekologinio saugumo įvertinimo priemonė, sukurta remiantis ekologinio saugumo modeliu, gali būti panaudota regiono plėtros saugumui stiprinti.

Darbo rezultatų aprobavimas

Ši disertacija paremta keturiais paskelbtais kritiniais straipsniais, iš kurių kiekvienas prisideda prie ekologinių grėsmių poveikio G20 grupės darniam vystymuisi ir regioninei plėtrai tyrimo. Šie straipsniai buvo paskelbti tarptautiniu mastu pripažintuose moksliniuose žurnaluose: vienas – *Web of Science* (WoS) duomenų bazėje, kiti recenzuojamuose leidiniuose ir konferencijų pranešimų medžiagoje, o tyrimų rezultatai buvo pristatyti tarptautinėse konferencijose ir moksliniuose seminaruose Lietuvoje bei užsienyje.:

Šių rezultatų sklaida įvairiose akademinėse platformose pabrėžia tyrimo aktualumą ir poveikį pasaulinei akademinei bendruomenei.

Disertacijos struktūra

Disertaciją sudaro įvadas, trys skyriai ir bendrojosios išvados. Disertacija yra 149 puslapių apimties, joje pateikiamas išsamus literatūros sąrašas ir autoriaus publikacijų disertacijos tema sąrašas. Joje taip pat yra 21 paveikslas, diagramos ir 26 lentelės, paskirstytos disertacijos pagrindinėje . Rašant disertacijos literatūros apžvalgą, iš viso buvo panaudoti 166 literatūros šaltiniai. Pirmame skyriuje aptariama, kaip ekologinių grėsmių, o ne kitų regioninių grėsmių, mastas daro įtaką regioninės plėtros užtikrinimui, remiantis aštuoniais saugumo srityje nustatytais darnaus vystymosi tikslais (DVT). Antras skyrius paremtas pirmame skyriuje aptartu regioninės plėtros užtikrinimu, saugumo rodikliai formuojami parenkant aštuonis su ekologinėmis grėsmėmis susijusius darnaus vystymosi tikslus saugumo srityje, tinkamą sistemą ir reikiamus kriterijus, reikalingus rodikliams pasirinkti kuriant modelį.

Trečiame skyriuje apžvelgiamas naujos valdymo priemonės, pagrįstos 2 skyriuje aptartu darnaus vystymosi (DV) užtikrinimo modeliu, kuris įvertina ekologinį saugumą G20 šalyse, kūrimas.

1. Teorinės įžvalgos apie tvarią ir saugią regioninę plėtrą

Šiame skyriuje nagrinėjama tvarumo (dar vadinamo darnumu) ir saugumo principų integracija į regioninę plėtrą. Pabrėžiama, kad vystant regionus yra būtina atsižvelgti į suformuluotus saugumo bei darnaus vystymosi tikslus (SDG).

Skyriuje nagrinėjami veiksniai, kurie trukdo tvariai regioninei plėtrai. Skyriuje nuosekliai argumentuojama, kad visoms valstybėms būdingos ekologinės grėsmės kenkia tvariai regioninei plėtrai.

Apžvelgiami įvairūs nesaugumo tipai, pristatomi įvairių autorių požiūris į saugumą. Grėsmės yra suskirstomos į kategorijas. Parodoma, kad greta tradicinių grėsmių, į kurias patenka karo grėsmė, yra ir netradicines grėsmės, tokios kaip kibernetinės ir ekologinės grėsmės. Yra pabrėžiama, jog ekologinės grėsmės turi tiesioginį poveikį regioninei plėtrai. G20 šalių plėtra yra itin veikiama.

Skyriuje nagrinėjamas tarptautinių organizacijų vaidmuo užtikrinant saugumą, įskaitant ir saugumą nuo ekologinių grėsmių. Grėsmėms valdyti yra kuriami modeliai, formuluojami regioninės plėtros teorijų teiginiai, siekiama atsižvelgti į aplinkos veiksnių tarpusavio ryšį.

Skyriuje pabrėžiama, jog šalims savo plėtroje būtina akcentuoti ne pridėtinės vertės kūrimą, bet tvarią ir ekologiškai saugią plėtrą. Tam turi būti numatytos tokį saugumą užtikrinančios priemonės, kurios padėtų neutralizuoti pasaulines grėsmes ir padėtų užtikrinti saugumo sąsajas su 17-a darnaus vystymosi tikslų. Tam, kad toks požiūris į regioninį saugumą būtų užtikrintas, reikia išspręsti saugumo aspektų aprašymo bei jų prioretizavimo klausimus.

Remiantis literatūros analize, gali būti suformuluoti tokie pagrindiniai teiginiai:

– 1. Regioninis vystymasis turi būti glaudžiai susijusi su tvarios plėtros, kuri remiasi trimis tarpusavyje susijusiomis posistemėmis (aplinkos, socialine ir ekonomine), principais.
– 2. Tvarios (darnios) plėtros aspektai negali būti nagrinėjami izoliuotai, jie turi būti siejami ir su nacionaliniu bei pasauliniu saugumu.
– 3. Siekiant sėkmingos regioninės plėtros, vykdant politiką tai plėtrai užtikrinti, reikia atsižvelgti į regioninių skirtumų priežastis bei identifikuoti problemas, kurios gali būti ekonominės, socialinės ir ekonominės, socialinės ir kultūrinės arba aplinkosauginės.
– 4. Tvari plėtra sinchronizuoja ekonominį, aplinkosauginį ir socialinį augimą, kad būtų didinama kartų gerovė ir kartu derinami kartų interesai, nepriklausomai nuo šalies išsivystymo lygio.
– 5. Darnaus vystymosi tikslai (DVT) – tai darnaus vystymosi gairės, kurios yra gerai subalansuotas ekonominių, socialinių ir aplinkosauginių tikslų ir uždavinių rinkinys.
– 6. Europos saugumo ir bendradarbiavimo organizacija (ESBO) susiejo saugumą ir vystymąsi, pasinaudodama kai kuriais darnaus vystymosi tikslais, kurie susiję su darnios plėtros užtikrinimu ir saugumo bei darnios plėtros sąsajų sprendimu.
– 7. Dauguma pavojingų regioninių grėsmių yra tarpvalstybinės, mišrios ir naujai atsiradusios, pavyzdžiui, klimato, vandens saugumo, geoinžinerijos ir patogenų grėsmės; šios šiuolaikinės regioninės grėsmės grindžiamos ekologinėmis grėsmėmis, keliančiomis grėsmę planetos saugumui.
– 8. Ekologinės grėsmės nėra išsamiai ištirtos. Todėl sutelkti dėmesį į jas ir su jomis susijusias grėsmes būtina, nes jos yra kitų grėsmių šaltiniai.
– 9. Nustatyta, kad išsivysčiusiose šalyse BVP sumažėjimo skirtumas yra didesnis nei besivystančiose šalyse. Vertinant ekologinių grėsmių poveikį darniai plėtrai šiuo atsižvelgiama į vieną makroekonominį rodiklį - BVP. Tuo tarpu ekologinių grėsmių poveikį tvariai regionų plėtrai reikėtų tirti naudojant ir kitus rodiklius.

Sistemų ir Regioninės plėtros teorijos gali būti pasitelkiamos regioninės plėtros valdymui, nes jos apibūdina posistemių tarpusavio ryšius sistemos viduje, jų tarpusavio priklausomybę bei leidžia įvertinti aplinkos įtaką regionų plėtrai.

2. Ekologinio saugumo modelio kūrimas

Šiame skyriuje daugiausia dėmesio skiriama tvarios ir saugios regioninės plėtros modelio, apimančio ekologinį saugumą, kūrimui. Įvertinami saugumo rodikliai, susiję su konkrečiais darnaus vystymosi tikslais, tai leidžia šalims įvertinti ir reitinguoti savo ekologinį saugumą ir padeda politikos formuotojams priimti sprendimus. Kitaip nei ankstesniuose tyrimuose, šiame tyrime pabrėžiamas ekologinių grėsmių poveikis regionų vystymuisi ir akcentuojama darnaus vystymosi tikslų apsaugojimo nuo šių grėsmių svarba.

Skyriuje aprašomas saugumo rodiklių sistemos formavimo procesas: atitinkamų DVT atranka ir ekologinių rodiklių parinkimo kriterijų nustatymas, reikalingas modeliui sukurti. Pabrėžiama, kad reikia turėti modelį, kuriame būtų atsižvelgta į naujai apibūdinto regioninio ekologinio nesaugumo poveikį DVT perspektyvai. Sukurtas tvarios ir saugios regioninės plėtros modelis grindžiamas DVT apsauga nuo ekologinių grėsmių, kurios kenkia šalių vystymuisi. Yra įvardijami DVT saugumo aspektai, susiję su ekologinėmis grėsmėmis, ir tada jie įvertinami naudojant parinktus ekologinio saugumo rodiklius. Ekologinio saugumo rodikliai, susiję su aštuoniais saugumo darnaus vystymosi tikslais (DVT), yra atrinkti iš Pasaulio banko duomenų bazės. Iš 1443 Pasaulio banko duomenų bazėje esančių rodiklių buvo išfiltruoti 404 SD rodikliai, o vėliau 43 saugumo SD rodikliai pagal aštuonis saugumo SDG.

Šio modelio pagrindu konstruojamas ekologinio saugumo valdymo įrankis, kuris padėtų įvertinti šalių plėtros rezultatus bei galėtų būti naudojamas šalių reitingavimui pagal teoriškai pagrįstus darnaus vystymosi parametrus.

Sukurtas saugumo modelis prisidėjo prie vadybos mokslo integruojant saugumo principus į darnų vystymąsi, siekiant sumažinti ekologines grėsmes G20 šalių grupėje.

3. Ekologinio saugumo valdymo priemonės kūrimas

Jame siekiama sukurti naują įrankį. Jo kūrime daugiausia dėmesio skiriama aštuonių darnaus vystymosi tikslų (DVT) ekologinio saugumo aspektams. Įrankio konstravimas yra grindžiamas tvarios ir saugios regioninės plėtros modeliu, pagal kurį vertinamas ekologinis saugumas regionuose. Mokslinis tyrimas orientuotas į G20 šalis. Siekiant gauti išsamius statistinius duomenis, naudotasi Pasaulio banko duomenų banku. Metodologinė prieiga paremta ekologinio saugumo rodiklių grupavimu arba klasterizavimu remiantis K-vidurkių metodu, ir rodiklių charakteristikų bei atitinkamai klasterių ryšių tyrimu, siekiant rasti pagrindinį klasterį, kuris leistų sukurti pagrįstą rodiklių sistemą. Iš 1443 Pasaulio banko duomenų bazėje esančių rodiklių yra sudaryta 15 tvarios ir saugios regioninės plėtros įrankyje naudojamų rodiklių sistema. Rodiklių sistema yra sugrupuojama pagal tvarumo aspektus, tada panaudojamas daugiakriteris sprendimų priėmimo metodas TOPSIS; vertinimai atlikti pasitelkus septynis ekspertus, rezultatai patikrinti naudojant konkordanciją ir $\chi 2$.

Pagal šį metodą iš alternatyvų rinkinio pagal kelis kriterijus atrenkama geriausia alternatyva ir tokiu būdu sukonstruojamas įrankis, kuri leidžia įvertinti ir reitinguoti ekologinio saugumo lygį kiekvienoje iš G20 šalių.

Sukurtas ekologinio saugumo įrankis leidžia suskirstyti G20 šalis į tris pagrindines grupes. Nesaugios šalys turėtų imtis ypatingų priemonių tam, kad neutralizuotų ekologines grėsmes, padidinant žemus tvarumo aspektų ir ekologinio saugumo rodiklius.

Šis įrankis yra naudingas parenkant atitinkamą ekonominę politiką, kiekvienai šaliai, taip, kad būtų minimizuotos ekologinės grėsmės veikiančios tvarią regioninę plėtrą. Sukurtas įrankis leidžia identifikuoti ekologines grėsmes, kurios būdingos vienai ar kitai šaliai. Sprendimus priimantys asmenys kiekvienoje šalyje nuspręs, kokių veiksmų imtis, atsižvelgiant į kiekvienos šalies taisykles, nuostatus ir politiką, imtis, kad būtų sušvelnintos pasirinktos ekologinės grėsmės.

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– Šio skyriaus 3.5 poskyryje pateikiami G20 šalių ekologinio saugumo vertinimo rezultatai.

Saudo Arabija (G20 šalių narė) buvo pasirinkta kaip pavyzdys, kaip taikyti sukurtą įrankį, kas aprašyta disertacijos pabaigoje.

Apribojimai

- Rezultatui būdingi tam tikri neapibrėžtumai ir išlygos, kai dėl žinių spragų ir matavimo problemų atsiranda neapibrėžtumas, pvz., matavimo paklaida, trūkstami duomenys ir duomenų rodiklių atkūrimas iš Pasaulio banko duomenų bazės.
- Kai kurie rodikliai buvo pašalinti, nes jų duomenų trūko daugiau kaip 75 %, o šios disertacijos autorius atkūrė rodiklius, kurių duomenų trūko mažiau kaip 25 %.
- Rinkti tik ekologiniai rodikliai, kurie kelia grėsmę darnaus vystymosi tikslams ir kurie pateikti Pasaulio banko darnaus vystymosi duomenų bazėje.

Disertacijos išvados leido išplėsti Sistemų bei Regioninio vystymo teorijas, nes atskleidė, kad ekologinės grėsmės turi būti įvertintos kaip veiksniai, darantys įtaką sistemų bei regionų vystymuisi.

Disertacijos rezultatų indėlis į regionų plėtros ir vadybos teorijas:

- 1.Regionų plėtros saugumo užtikrinimas yra dinamiška sritis, kuri nuolat vystosi, atsirandant naujiems iššūkiams ir galimybėms, todėl politikos formuotojai ir planuotojai gali remtis šiomis teorijomis rengdami intervencijas, skatinančias darnų vystymąsi, apimančias darnaus vystymosi saugumą įvairiuose pasaulio regionuose.
- Disertacijos išvados prisidėjo prie Regioninės plėtros teorijos, integruojant saugumo principus į regioninę plėtrą, vertinant regioninį ekologinį saugumą, o ne sprendžiant tik globalios aplinkos blogėjimo klausimą.
- Lyginant su klasikiniais Regioninės plėtros teorijos teiginiais, akcentuojančiais ekonominio vystymosi naudą pasireiškiančią įvairiapusišku ekonominės gerovės kilimu, disertacijoje teigiama, jog tai gerovei pasiekti yra būtinas išteklių, aplinkos ir vystymosi santykio koordinavimas; yra pabrėžima, jog siekiant darnios regionų plėtros, ekologinio saugumo principų integravimas į darnaus vystymosi tikslus yra būtinas.
- 2.Disertacijos išvados prisidėjo prie Sistemų teorijos, nagrinėjant rodiklių, turinčių įtakos šalių darniam vystymuisi, bei jų ekologiniam saugumui, poveikį. Praplėsta Sistemų teorija gali turėti praktinės reikšmės siekiant tvarios ir saugios šalių ar jų grupių plėtros.

Šio 3 skyriaus tema buvo publikuotas straipsnis „Šalių ekologinio saugumo matavimas“ (Chehabe Edine et al., 2023) (WoS).

Bendrosios išvados

1. Mokslinės literatūros analizė atskleidė įvairius požiūrius į tvarumą ir saugumą. Integruodamos saugumo aspektus į darnų vystymąsi, organizacijos ir vyriausybės gali sustiprinti šalių atsparumą įvairioms grėsmėms. Planuojant tvarų regioninį vystymąsi, labai svarbu įvertinti ekologinį nesaugumą ir formuluoti regioninio vystymosi tikslus pagal regionui būdingas savybes, sutelkti dėmesį į gamtinę aplinką. Į sukurtą regioninės plėtros modelį yra integruojami saugumo principai ir taip atsižvelgiama į šiuolaikinių ekologinių grėsmių poveikį šalių vystymuisi. Šis požiūris leidžia papildyti tvarios plėtros principus bei sukonstruoti ekologinio saugumo matavimo įrankį.
2. Daugiakriteris sprendimų priėmimo metodas TOPSIS buvo pasirinktas todėl, kad jis leidžia aiškiai išdėstyti alternatyvas pagal jų artumą idealiam sprendimui. Jį lengva suprasti ir įgyvendinti, jis gerai apdoroja kokybinius ir kiekybinius duomenis ir dėl savo paprastumo, aiškumo ir gebėjimo apdoroti daugelį kriterijų pusiausvyros puikiai tinka ekologiniam saugumui vertinti, todėl šis metodas yra geras pasirinkimas regioninei plėtrai vertinti. Rezultatas įgalina turėti įrankį, kurį galima naudoti šalių ekologinio saugumo būklei vertinti.
3. Platus spektras grėsmių, su kuriomis susiduria daugelis šalių, reikalauja naujo požiūrio į regioninę plėtrą. Ligi šiol regioninė plėtra dažniausiai asocijuodavosi su tvarios (dar kitaip vadinamos darnia) plėtros uždaviniais. Buvo tradiciškai svarstoma, kaip įvertinti plėtros tvarumą. Šioje disertacijoje klausimas keliamas kiek kitaip: siūloma integruoti saugumo aspektus į tvarios plėtros tikslus. Saugumas yra plati sąvoka. Disertacijoje yra aptariamos nesaugumo rūšys, grupuojamos jas lemiančios grėsmės. Klasikinė – ginkluoto konflikto, karo grėsmė yra tik paminėta, ji plačiau neanalizuojama. Disertacijoje susikoncentruojama į ekologines grėsmes. Sukonstruojamas tvarios ir saugios regioninės plėtros modelis. Jo pagrindu yra sukuriamas įrankis, leidžiantis įvertinti G20 šalių plėtrą, susitelkiant į ekologines grėsmes. Įrankis sukurtas remiantis pagrįsta rodiklių sistema, sudaryta iš 15 rodiklių, bei pasinaudojant daugiakriteriu metodu TOPSIS. Sukurtas saugumo įrankis matuoja ir reitinguoja šalies ekologinį saugumą, tai leidžia šį įrankį naudoti G20 šalių, kurių duomenys buvo naudojami darbe, tvariai ir saugiai plėtrai valdyti.
4. Disertacijos mokslinis naujumas susijęs su sukurtu modeliu bei įrankiu. Autorius suformuluoja ginamuosius teiginius ir apibūdina rezultatų indėlį į vadybos mokslą.

Mohamad CHEHAB EDDINE

MANAGEMENT OF SUSTAINABLE AND SECURE
REGIONAL DEVELOPMENT

Doctoral Dissertation

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