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RIGA TECHNICAL UNIVERSITY

Vita Brakovska

METHODS FOR THE DEVELOPMENT OF A CLIMATE-RESPONSIBLE FUTURE SOCIETY

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Natural Sciences and Technology
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Acknowledgement for the “Valuable Challenges”

To paraphrase the words of the innovator and Apple co-founder Steve Jobs on connecting the dots of the past to create a better future, I now see how these four years of my “hero’s journey” (Joseph Campbell) have led me to a place where I approach daily and professional challenges from a more diverse perspective than ever before. Not only do I look through these lenses myself, but I also aim to help others adopt these different “glasses” to assess the most suitable approaches for specific goals.

This journey has brought invaluable knowledge and insights acquired through my doctoral research, some of which emerged in the final stages of this project. Like a pilot stepping into an aircraft to view their work from above, I found myself exploring not if but how I could further strengthen the practical application of my research’s scientific contributions in my daily work and enhance its societal impact.

Therefore, I extend my heartfelt thanks to many people who each completed their part in this journey, helping me find answers to these essential questions:

- to Tenure Professor Dr. sc. ing. Andra Blumberga, for her insights into the world of systems thinking, which opens up yet-untapped possibilities for working with complex social systems;
- to Professor Dr. habil. sc. ing. Dagnija Blumberga, for her remarkable patience, trust, and the freedom she granted me in choosing my research topic – motivating me in the most challenging moments of this journey;
- to the organisations and their representatives, especially from planning regions and municipalities, with whom we tested methods of societal relevance for developing a climate-resilient society;
- to Dr. oec. Renāte Lukjanska, who years ago shared the memorable words, “If you want to break through your glass ceiling, enrol in a Ph. D. program”;
  to Professor Dr. sc. ing. Jūlija Gušča, whose collaboration allowed me to delve into environmental engineering, recognise its practical value in my professional path, and open doors to a world filled with vital knowledge for humanity;
- and, of course, to my family, who supported and helped me maintain balance, ensuring that not once (!) during these four years did I consider giving up.

I am eagerly looking forward to applying the findings of this research to build better governance practices in Latvia for the development of a climate-resilient society together with like-minded colleagues!

DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for defence at the open meeting of the RTU Promotion Council on 28 November 2024 at 14.00 at the Faculty of Natural Sciences and Technology of Riga Technical University, 12/1 Āzenes Street, Room 607.

OFFICIAL REVIEWERS

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for review to Riga Technical University for promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis has not been submitted to any other university for promotion to a scientific degree.

Vita Brakovska (signature)

Date: 29.10.2024.

The Doctoral Thesis has been written in Latvian. It consists of an Introduction, three chapters, Conclusions, 53 figures, and 30 tables; the total number of pages is 209. The Bibliography contains 154 titles.

TABLE OF CONTENTS

INTRODUCTION

Topicality of the Thesis

In fostering a climate-responsible society, an educated, motivated individual capable of making decisions grounded in community interests plays a crucial role. Such an individual's attitudes and behaviors towards the environment not only significantly influence the effectiveness of various support measures [1], [2] but also shape entrenched perceptions [2] about societal norms [3], rooted fundamentally in cultural behaviors [4].

The relevance of this research is underscored by the observation that technologies developed through scientific–industry collaboration and public-sector support instruments aimed at mitigating climate change do not yet show the desired outcomes [5] or momentum. Attention to individuals' mental models is particularly pertinent given the insufficient progress achieved under the European Green Deal, indicating a need for new methods that merge technology and support mechanisms with systematic approaches to influencing individual attitudes and behaviors in decision-making for climate-neutral actions.

The need for this research is further highlighted by the growing demand for systemic solutions [6], that are attuned to the spirit of the times, shifting social norms [7] and behavior culture to suit the varied profiles of different social segments. Tools designed to build a climate-responsible society must be integrated not only within environmental and climate education but also into cultural and creative industry activities that encompass a broader range of interests and interactions. This includes personal development, socio-economic development, productivity, and other processes where members of society can exercise their civic interests.

A key challenge lies in adapting environmental education and awareness activities to various social disciplines, thereby extending reach to broader and previously challenging-to-engage target groups. Future research and development in this field will largely depend on the quality of collaboration between social and environmental engineering sciences to establish the foundations for a climate-responsible society. This process must consider the specific needs and objectives not only of target groups but also of stakeholders [8] partner organizations such as municipalities, businesses, non-governmental organizations, regional planning bodies, and state institutions – by incorporating the research-developed methods into systemic solutions within organizations.

The urgency of this research also stems from the fact that theoretical and applied research in this field is still in its early stages [9] and the literature lacks comprehensive studies on interdisciplinary approaches within social and engineering sciences to advance a climate-responsible society at local and regional levels [10].

Goal and Tasks of the Thesis

This study aims to develop and test contemporary methods for engaging partner organizations in working with diverse target groups to foster a society that is informed and educated on climate change issues, and capable of taking responsibility for attitudes and behaviors that contribute to achieving climate neutrality goals. To fulfil this research aim, the following objectives have been set:

1. To analyze and assess individual behavior patterns and awareness regarding climate change, identify shortcomings in current efforts, and recognize potential directions for promoting climate-responsible actions.
2. To develop and validate a set of methods and interventions for working with diverse target groups to influence understanding, intent, and action in relation to climate change. The method set created within this study will foster education, engagement, critical thinking, and the acquisition of new experiences within the context of climate neutrality.
3. To apply scientific innovation to strengthen efforts towards achieving climate neutrality goals by offering theoretically grounded and practically tested approaches for engaging target groups.

Hypothesis

The study posits the hypothesis that access to a diverse range of tools contributes to the development of a climate-responsible society, influencing three key aspects of individual behavior:

1) awareness and education – information related to climate change is adapted and integrated into a variety of publicly accessible events tailored to individual interests (including cultural and creative industry products related to climate change, public involvement in sustainable development planning, lifelong learning themes related to environmental sciences, critical thinking, organizational culture oriented towards climate neutrality, and other fields);
2) demonstration of attitudes and intent – application of various interactive tools (such as collaboration, co-creation, visualization of outcomes, critical thinking, etc.) in public events to foster the acceptance of new norms;
3) behavior-promoting environment – a physical and cultural setting that encourages conscious behavior, creating a supportive background for individual expression.

Scientific Novelty of the Thesis

The scientific novelty of this work lies in the development, analysis, and validation of five tools grounded in six scientific approaches to strengthen climate-responsible engagement within society:

1) digital twin of energy communities;
2) simulation game (analog format of the digital twin);
3) sustainability hackathon;
4) future organization game;
5) systems thinking workshop.

Interdisciplinary tools for fostering a climate-responsible society remain underexplored in Latvia. Thus, the methodology integrates a synergy of social and engineering sciences in creating these tools. Consequently, this work provides a significant contribution to implementing innovative approaches toward achieving climate neutrality within the framework of the European Green Deal.

Practical Applicability and Value

The methodology proposed, which underpins the scholarly value of this work, has already become a practical tool for developing sustainable strategies at the regional and municipal levels throughout this research. It provides a variety of approaches to engage local communities in progressing toward climate neutrality. Upon completion of the research and consolidation of its findings, the methods validated in this dissertation will contribute to achieving sustainability goals within public and private sector organizations by offering:

1) broader public engagement through innovative content and formats;
2) more inclusive approaches to working with diverse target groups;
3) support for building social capital within organizations aiming for climate neutrality;
4) enhanced governance capacity to address climate change mitigation issues;
5) interactive tools to promote climate-conscious attitudes as a new societal norm, ultimately enabling more harmonious adaptation of complex social systems to new realities.

This study is of substantial importance as it provides insights into engaging diverse interest groups and shifting their cognitive paradigms, necessitating solutions founded on collaboration between social and engineering sciences.

The validated methods will be especially useful for the 24 Latvian municipalities that have joined the prospective European Union Covenant of Mayors for Climate and Energy. By voluntarily committing to climate neutrality goals, these municipalities can leverage the developed tools to more effectively interact with local communities, using diverse approaches to foster public understanding of the need to adapt to emerging conditions.

The findings from this study are applicable to cultural and educational needs at the local governance and regional planning levels, as well as in broader societal development areas related to quality of life, particularly in organizing events and training dedicated to sustainability topics. The methods are also valuable for preparing specialists within these disciplines.

The research theses, methodological approaches, and associated publications are already used as references in pedagogical, social, and academic work, as the author collaborates with students from Latvian and international universities, as well as various societal groups and experts across all Latvian planning regions. This collaboration includes contributions to the preparation of a methodological guide by the Ministry of Welfare of the Republic of Latvia for social workers on community collaboration and sustainability (Methodological Guide for Social Work in Communities), which promotes diverse dialogue and cooperation approaches to raise awareness of the consequences and impacts of attitudes and actions on sustainable socio-economic development.

According to the United Nations Sustainable Development Goals analysts, up to 65 % of the 169 sub-goals are related to actions within municipal competencies, making the local government level a critical component in achieving these objectives.

An essential part of this research is the publication “Thinking and Creativity” in the Latvian Language Agency’s scientific-methodological publication “NOW,” which provides support tools for general education school teachers in developing creative skills among students. This fosters the use of diverse approaches in addressing complex issues, including those related to climate change, in students' future endeavours [11].

This study has significant practical implications, driven by the author’s efforts to develop and deliver content that meets contemporary demands for public events organized by EU, national, regional, and municipal partners (European Parliament, Latvian National Culture Centre, regional planning entities, municipalities, educational institutions, business associations, etc.) aimed at actively engaging their target audiences in sustainability issues. The balanced application of social and engineering disciplines in interactive tools is the only known format in Latvia.

The tools developed within this study have been validated through collaboration with various sectors, including the public sector (municipalities, planning regions), state and municipal enterprises, and the non-governmental sector.

Approbation of the Thesis

The results of the Thesis have been presented at five conferences and published in nine scientific articles. The study's findings have been discussed and demonstrated at the following international conferences:

1. V. Brakovska, “Green Culture in the Smart City as a supportive environment for the sustainable company”, 9th Annual Entrepreneurship and Innovation Conference, Estonian Entrepreneurship University of Applied Sciences, 2021.
2. V. Brakovska and A. Blumberga, “The Influence of Young People on Household Decisions on Energy Efficiency in Latvia”, International Scientific Conference of Environmental and Climate Technologies – CONECT 2023, Riga Technical University, 2023.
3. V. Brakovska, R. Vanaga, G. Bohvalovs, L. Fila, and A. Blumberga, “Multiplayer game for decision-making in energy communities”, Sustainable Energy Planning and Management, Aalborg University, 2023.
4. V. Brakovska, “From Energy Communities to Collective Synergy in Business: Knowledge Transfer for Addressing Social Dilemmas in Entrepreneurship”, 3rd IEEE-TEMS International Conference on Technology and Entrepreneurship (ICTE), Kaunas University of Technology, 2023.
5. V.Brakovska, R.Vanaga, Ģ.Bohvalovs, A.Blumberga, D. Blumberga, “Climate Conscious Communities: Navigating Transformation through Simulation Games

and Creative Engagement", International Scientific Conference of Environmental and Climate Technologies – CONECT 2024, Riga Technical University, 2024.

Scientific Publications

1. G. Bohvalovs, R. Vanaga, V. Brakovska, R. Freimanis, and A. Blumberga, "Energy Community Measures Evaluation via Differential Evolution Optimization", Environmental and Climate Technologies, vol. 26, no. 1, pp. 606–615, Jan. 2022, https://doi.org/10.2478/rtuect-2022-0046
2. V. Brakovska, R. Vanaga, G. Bohvalovs, L. Fila, and A. Blumberga, "Multiplayer game for decision-making in energy communities", International Journal of Sustainable Energy Planning and Management, vol. 38, pp. 1–13, Jul. 2023, https://doi.org/10.54337/ijsepm.7549
3. A. Kalnbalkite, V. Brakovska, V. Terjanika, J. Pubule, and D. Blumberga, "The tango between the academic and business sectors: Use of co-management approach for the development of green innovation", Innovation and Green Development, vol. 2, no. 4, p. 100073, Dec. 2023, https://doi.org/10.1016/j.igd.2023.100073
4. V. Brakovska and A. Blumberga, "The Influence of Young People on Household Decisions on Energy Efficiency in Latvia", Environmental and Climate Technologies, vol. 28, no. 1, pp. 45–57, 2024, https://doi.org/10.2478/rtuect-2024-0005
5. A. Blumberga, I. Pakere, Ģ. Bohvalovs, V. Brakovska, R. Vanaga, U. Spurins, G. Klasons, V. Celmins, D. Blumberga, "Impact of the 2022 energy crisis on energy transition awareness in Latvia", Energy, Volume 306, 2024, 132370, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2024.132370
6. V. Brakovska, "Domāšana un radošums", Zinātniski metodisks izdevums "TAGAD", Latvijas valodas aģentūra, ISSN 1407-6284, Jan 1, 2018 (11), https://maciunmacies.valoda.lv/wp-content/uploads/2019/10/TAGAD_1.2018_web_small.pdf
7. Autoru kolektīvs, "Metodiskais materiāls sociālam darbam kopienā", Latvijas Republikas Labklājības ministrija, ISSN 2661-5371, 2023, https://www.lm.gov.lv/lv/media/24606/download?attachment
8. Under review: Brakovska, V., Vanaga, R., Bohvalovs, Ģ., Blumberga, D., Blumberga, "Climate Conscious Communities: Navigating Transformation through Simulation Games and Creative Engagement" CONECT 2024: XVII International Scientific Conference of Environmental and Climate Technologies: Riga Technical University, 2024. ISBN 978-9934-37-065-6. ISSN 2592-9704. https://doi.org/10.7250/CONECT.2024.032
9. Under Review: A. Blumberga, V. Brakovska, R. Vanaga, G. Bohvalovs, and R. Freimanis, "Single player game for decision making in energy communities", Energy Proceedings, Vol 29, 2024, ISSN 2004-2965, https://doi.org/10.46855/energy-proceedings-11276

Structure of the Thesis

The Doctoral Thesis consists of a collection of nine contextually related scientific publications, published in various academic journals and accessible for citation in international databases, including the Web of Science and Scopus. The primary focus of the research is on methods that promote the development of a climate-responsible future society, utilizing six scientific approaches (see Fig. 1).

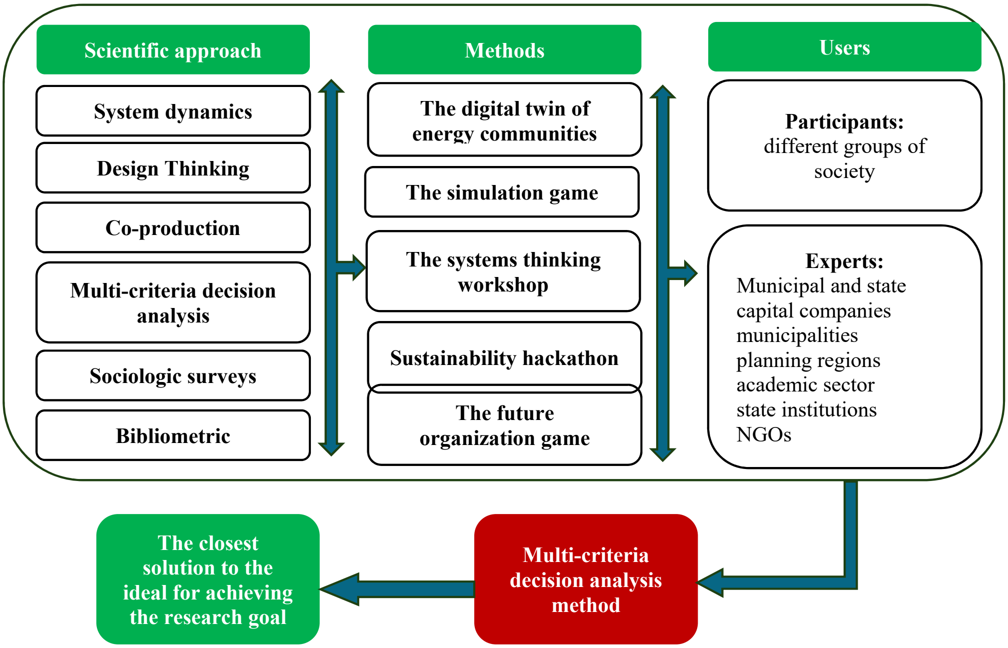

Fig. 1. The structure of the Thesis.

The Doctoral Thesis consists of an introduction and three chapters: a literature review, research methods, and results and discussion. The introduction outlines the research aim and objectives, presents the hypothesis, and describes the scientific significance and practical applications of the Thesis. It also provides information on the validation of research results, which includes participation in international scientific conferences, the development of scientific publications, and the practical implementation and evaluation of the methods developed within the study.

The first chapter is dedicated to a literature review analyzing the challenges and opportunities associated with developing a climate-neutral society, aiming to identify gaps in research related to individual behavioral aspects in climate change mitigation. The second chapter describes the research methodology, which is based on the application of six scientifically grounded approaches for the development and validation of five methods. The third chapter presents the results and their analysis in the context of the proposed hypothesis. Finally, conclusions are drawn based on the analysis of the obtained results.

1. METHODOLOGY

The Thesis employs six scientific approaches to validate the methods developed for fostering a climate-responsible society. Figure 1.1 illustrates the scientific approaches explored in this study.

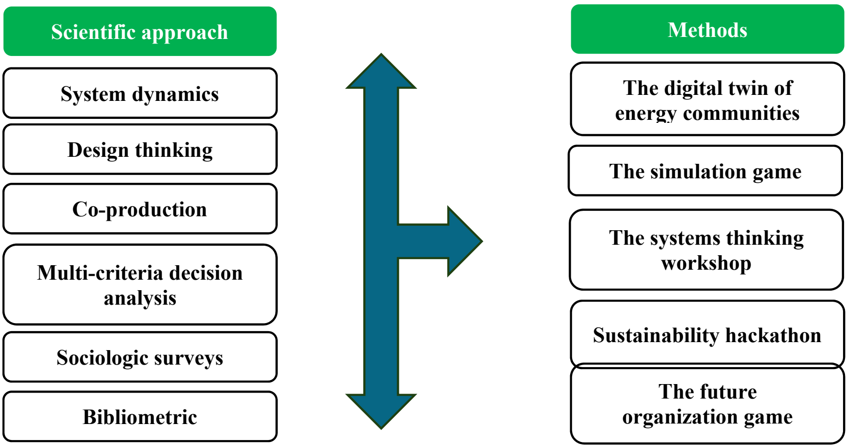

Fig. 1.1. The scientific approaches used in the Thesis for the development of new methods.

The application of methods based on scientific approaches can be sequential, aiming to create a gradual impact – from raising awareness to establishing an environment that stimulates individual action among the target groups selected for the study. However, if only one type of impact is required, an appropriate tool can be selected accordingly.

Throughout the research process, the author also leveraged extensive experience from professional practice in working with various social groups and public and private sector organizations involved in sustainable development.

In addition to sociological surveys, three target groups were engaged in the validation of certain methods within the study (see Table 1.1): municipal employees, entrepreneurs, and youth (including students of environmental engineering).

Table 1.1

The Target Groups Involved in the Study and the Rationale for Their Selection

#	Target group	Justification
1.	Municipal employees, especially in matters of development planning, culture and education	Management of administrative resources Development of sustainability processes in the community
2.	SMEs with more than ten employees	Productivity tools for staff development in the context of the company's sustainable operation
3.	Young people aged 14 to 25 years	A mental model for building influence

The choice is based on the author's practical experience working with these segments and observations on diverse formats for influencing these target groups in developing a climate-responsible society. Municipal employees bring access to administrative resources for planning and implementing sustainability-focused activities within local communities; entrepreneurs show motivation to explore new tools for guiding their personnel towards climate neutrality; and youth demonstrate a desire to shape their impact on climate change mitigation.

The scientific approaches chosen in this study are applied not only for developing and evaluating the effectiveness of methods but also for assessing the role of data visualization as a tool to influence individual attitudes and behavioural culture. This approach aims to offer new formats for demonstrating and reinforcing perception norms within a broader society [12].

1.1. Sociological Surveys

Sociological surveys are a commonly used approach in academic research within the field of sociology. This method involves data collection by asking respondents questions about various social phenomena, beliefs, behaviours, or experiences.

Two surveys were conducted between September 17–21, 2021, and March 27–28, 2023, using a computerized web interview method. The fieldwork for the surveys was carried out by the SKDS research centre. The total population surveyed included over 1.5 million Latvian residents aged 18 to 75. A quota sampling method was used for sample selection, with identical questionnaires in both surveys aimed at reaching 1,000 respondents. The questionnaire data consists of five thematic blocks, listed in Table 1.2.

Table 1.2

Thematic Blocks of the Sociological Survey

Characteristics of respondents according to socio-demographic parameters	**Energy efficiency practices at the level of housing, buildings and communities**	**Determinants of improving energy efficiency**	**Description of the possibilities for implementing energy efficiency improvements at the building level**	**Public and social activity of residents, involvement in various types of community events**
Gender, age, nationality, education, place of residence, employment status, marital status, type of housing, year of construction, ownership of housing, type of management, personal involvement in housing management	Heat and electricity saving, energy production, mobility (environmentally friendly transport, transport sharing)	Factors influencing people's choice to make or not to make energy efficiency improvements in their home or building: environmental impact, quality of life, value of their real estate, financial investment and payback period, available state support for improvements, expert advice	Agreement with neighbours on increasing energy efficiency in an apartment building, choosing a building manager, repairing staircases, repairing the facade of the building, replacing the roof of the building, changing the window of the building, installing solar panels, changing the type of heating of the building, installing a bicycle shed, etc.	Environmental cleaning, team sports games, further education, joint neighbourhood activities, public consultations, non-governmental organizations, religious congregations, political parties, etc.

Data processing was conducted using the SPSS statistical software package. In certain survey questions, five-point Likert scale response options were used [13], [14]. Multiple tests were applied to compare the results of the two surveys for Likert-type data. Firstly, an independent samples t-test was introduced to assess the equality of means. Although the t-test generally shows strong statistical power [15], some have raised concerns about its use with Likert-type items, as these responses and the ordinal data they produce are discrete [16]. Therefore, as a nonparametric alternative, the Mann–Whitney U test was conducted to examine whether the two samples came from populations with the same distribution function. The Mann–Whitney U test does not rely on means and standard deviations but instead ranks all observations from both samples and compares the sum of these ranks [17].

The content required for developing the tools intended for validation is derived from the research and sociological survey conducted in 2021, including interpretations of residents' attitudes toward energy efficiency issues. The second phase of the sociological survey in 2023 was designed to capture sociological data characterizing changes in residents' energy efficiency practices and attitudes toward climate change issues following 2022, when rising energy costs significantly impacted household expenditure structures.

1.2. System Dynamics Method

The method, developed by Professor Jay Wright Forrester of the Massachusetts Institute of Technology (MIT), combines qualitative and quantitative analysis [18] and was initially created for business managers to help understand production processes. However, it has since found broader application in policy analysis and implementation within both the private and public sectors. The development of the system dynamics model is illustrated in Fig. 1.2 [19].

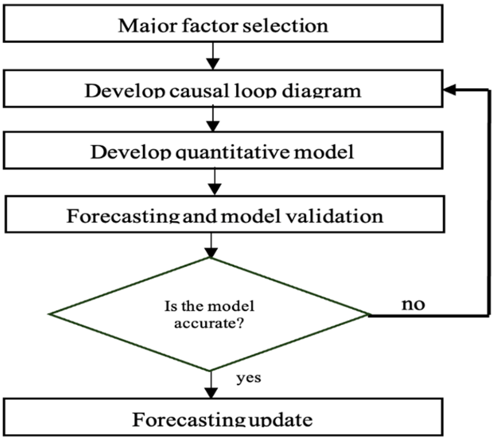

Fig. 1.2. Stages of the system dynamics model development process.

Using computer simulation software (such as Stella Architect or Vensim), parameters or strategies can be adjusted to simulate and predict how various system elements interact and change their behaviour under specific conditions over time [20]. This approach aids in developing meaningful strategies for solving complex problems, especially in cases where system behaviour cannot be fully explained by the behaviour of its individual elements, as the system and its components possess distinct characteristics.

The validation of the scientific approach is conducted through the development of two distinctly different tools – a technology-based tool and an analog interaction format. The creation of the analog format is justified by the need to make the benefits associated with digital tools more accessible to audiences with varying levels of digital proficiency, thereby ensuring the achievement of the study's objectives when engaging with diverse societal groups. Both tools include a simulation for the development of an energy community, which relies on individual collaboration toward a shared goal, such as reducing CO_2 emissions.

The Digital Twin of the Energy Community

The system dynamics-based digital tool, the digital twin of the energy community, is being developed as a platform for collaboration and joint decision-making in energy efficiency within potential energy communities consisting of multiple residential buildings within a single neighbourhood. This tool can also provide an assessment of which climate and energy policies have the most significant impact on promoting energy transition solutions.

The goal of this tool is to enable users to evaluate the impact of their decisions on individual and collective interests and to adjust their choices until the decisions meet the community's needs. Within the simulation, interaction between users and data visualization supports optimal resource utilization from both a time and technological perspective, encouraging users to review their decisions to achieve the community's objectives, such as reducing CO_2 emissions.

During the simulation, participants are presented with a hypothetical scenario and a predefined collective goal, allowing them to select methods to achieve the target [21] – energy saving, energy production, or shared use of transportation resources (see Table 1.3).

Table 1.3

Types of Energy Efficiency Measures

Energy efficiency	Energy production	Transportation
Insulation of roof, walls, and basement Window replacement Ventilation replacement Appliances replacement	Solar panels by indicating: • Roof area used for production • Proportion of solar panels from the area used for roof production	Frequency of use Travel distance Vehicle sharing

Thus, the tool plays a vital role by visualizing various decision-making indicators in real time (see Table 1.4). It provides participants with a valuable educational environment where they can observe the consequences of their own decisions and those of other simulation participants, as well as the impact on the community's gains and losses. Participants join the simulation by entering a fictional, non-identifiable username and team name. The simulation proceeds after participants have listened to audiovisual guidelines explaining the basic principles and steps of the tool's operation.

Data visualization and interaction among participants enhance awareness and education, which are crucial for fostering individual climate responsibility. The author believes that engaging with this tool can help create a stimulating environment that encourages more climate-responsible behaviour in the future, particularly concerning energy efficiency measures. The effectiveness of the tool is evaluated by its users, and the results are discussed in Chapter 2.

Table 1.4

Indicators of Decision-Making, Including both Individual and Community Goals

Specific	Financial	Percentages	Absolute
Heat consumption, kWh/m^2 Heating, kWh/m^2 Electricity, kWh/m^2 Energy, kWh/m^2 Investment, EUR/m^2	Costs, EUR/ year Heat costs EUR/year Transportation costs, EUR/ year Transportation costs EUR/100 km Investment, EUR Savings, EUR/ year Payback time, years	Change in heat consumption, % Change in electricity consumption, % Change in electricity costs, % Self-sufficiency share, % Self-consumption share, % Change in car usage, %	Heat consumption, kWh Transport energy consumption, kWh Heat emissions, t Electricity emissions, t Transport emissions, t Surplus heat produced, kWh Surplus electricity produced, kWh

The model calculates the energy balance at both the building and community levels using standard climate data with a simulation period of one month. Energy can be generated on-site through solar panels and collectors, heat pumps, thermal storage tanks, batteries, and electric vehicles. External solar energy production, integrated with the electrical grid, is included as an additional option in the policy simulation tool to assess the potential impact of this solution. However, other external renewable energy technologies are excluded from this model version, as Latvia generally prioritizes large photovoltaic fields over wind power plants.

Each of the five sectors contains various input variables with default values (e.g., technical parameters of technologies, costs, outdoor climate, emission factors) and adjustable variables for users (e.g., energy prices, fuel types, indoor climate). Key performance indicators in each sector illustrate the impact of different intervention measures on energy demand, transportation, on-site production, and storage, including total investments, payback periods, energy consumption, and greenhouse gas emissions. The primary performance indicators of the energy community include total energy consumption, energy costs, emission levels, monthly energy balance, payback time, and other building parameters. A detailed model structure is available in the publication "Evaluation of Energy Community Measures Using Differential Evolution Optimization", included in the publication set.

Users can select one of six predefined building categories based on the most common standardized apartment buildings in Latvia, built between the 1950s and 1980s.

The Stella Architect software is used to gather data and develop a user interface. This interface allows users to input data and initiate the simulation following guidelines presented in both audiovisual and written formats.

The tool's user interface, which displays community-level initiatives, state-level policies, and key performance indicators for each building type and community, is illustrated in Fig. 2.3. This interface includes various energy efficiency measures on the demand side, such as improving the thermal insulation of building envelopes, lowering indoor temperatures, changing habits, upgrading equipment, and installing smart technology and ventilation systems.

The model also includes transportation measures (car sharing, daily mileage, weekly car usage) as well as on-site energy production technologies (solar photovoltaic panels and collectors) and storage (electricity and thermal).

Additionally, it accounts for external renewable energy sources (wind turbines and solar panels) that can be combined at the community level to increase overall energy consumption and achieve specific community carbon emissions reduction targets.

State-level policies incorporated into the tool include heat and electricity prices, investment subsidies for building energy efficiency measures, subsidies for electric vehicles, grants for rooftop solar installations (solar panels and collectors), the option to sell surplus solar electricity at market prices, net metering systems for solar energy surpluses [22], the introduction of Green Certificates to specify the origin of grid electricity [23], emission taxes, and total energy costs from fossil fuels, as well as adjustments in loan terms and interest rates.

Users are given the opportunity to adjust their behaviour, such as changing room temperature. They can also modify energy-saving or production measures according to their preferences, for example, by adjusting the proportion and intensity of solar panel deployment on the building's roof (see Fig. 1.3).

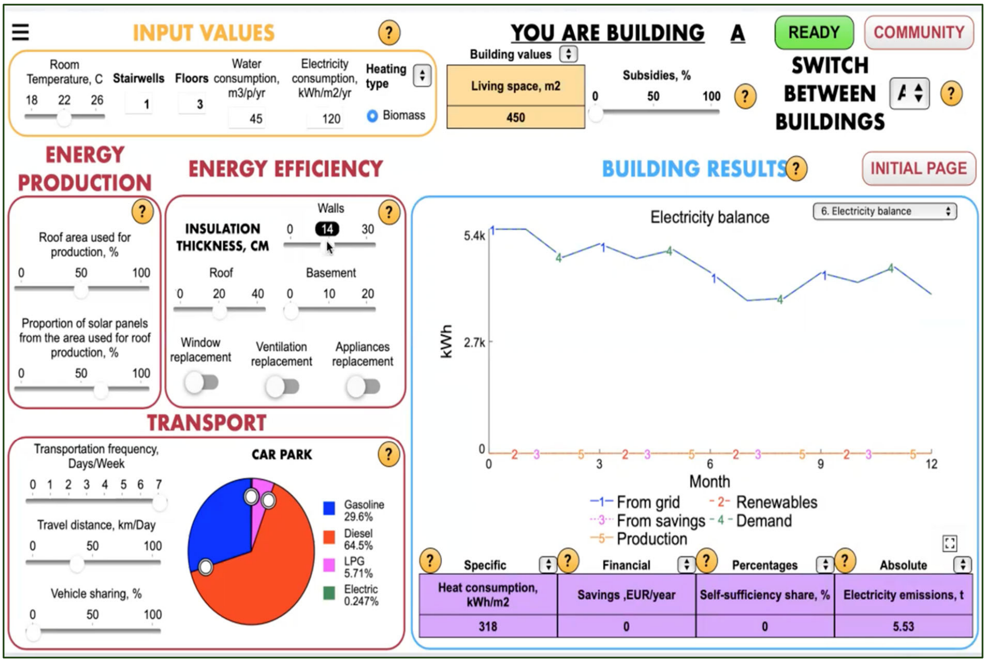

Fig. 1.3. Tool user interface for community-level actions, country-level policies and key performance indicators for each building type and community.

A more detailed description is provided in the attached scientific articles, “A Multiplayer Game for Decision-Making in Energy Communities” and “Evaluation of Energy Community Measures Using Differential Evolution Optimization”, included in the publication set.

The system dynamics model integrated into the tool incorporates a social dilemma arising from balancing individual (economic) interests, such as savings and payback period, with community interests, such as reducing emissions from heating, electricity, and transportation. This dilemma is influenced by heterogeneous consumer motivations, social interactions, and individual adoption decisions over time.

Players are required to assess their decisions by considering their impact on the entire community over multiple sessions and to adapt in order to reach decisions that satisfy the preferences of the entire community (involved players). The developed tool provides real-time tracking and display of all player behaviours in a single simulation, allowing participants to observe how individual decisions affect the community’s overall outcomes and environment. A detailed description of the tool is available in the article “A Multiplayer Game for Decision-Making in Energy Communities,” included in the publication set.

The Simulation Game as Analog Format

Scientific research enhances the contribution of environmental engineering toward achieving climate neutrality goals, offering insights into the impact of various methods on climate change and promoting the availability of diverse solutions and engagement with different societal groups [24]. Within this study, an analog version of the Energy Community Digital Twin – a role-playing simulation game – was developed based on the system dynamics approach. This analog format makes the tool accessible to a wider audience with varying levels of digital skills.

The objective of the tool is to improve users' ability to collaborate in situations where individual interests must be adjusted to align with collective goals in the context of climate change mitigation, which may require changes in initial perspectives.

The study focuses on aspects such as individual awareness and education regarding climate change and energy efficiency, attitudes and behaviors, the balance between self-interest and collective interests, as well as engagement in collaborative processes, including co-creation[25]. This ensures a balanced social and engineering sciences contribution to understanding the cognitive and behavioral models of target groups.

The primary task of the tool is not only to enhance user education but also to foster interest in environmental engineering as a practically applicable discipline, crucial for informed future decision-making within the context of climate-responsible behavior.

The structure of the simulation game includes three essential aspects that directly impact individuals:

1. Knowledge of climate change and energy efficiency measures: Participants are provided with information on climate change and energy efficiency measures, which aids in making informed decisions.

2. Set of scenarios: This aspect includes the behaviors of community members and characterizations of individual goals, positioning each player within realistic community conditions where their choices are influenced by the arguments and actions of other participants.

3. Supportive environment: The environment comprises the priorities and policies set by local authorities to mitigate climate change, along with available infrastructure, technology, and material resources that encourage participation in energy efficiency initiatives.

In the simulation game, each participant is assigned one of six roles (see Fig. 1.4), each defined by a specific social profile based on occupation, personal beliefs (denial, conservative, progressive approach), and attitude toward climate change (sceptic, neutral, optimist). Role descriptions are enhanced with visual images and character traits to help participants engage more fully in their roles. Similar to the digital simulation, participants are tasked with achieving a common goal – reducing CO_2 emissions – by agreeing on one or two energy efficiency measures to implement collaboratively.

Fig. 1.4. Simulation game roles.

The structure of the simulation game is detailed in Table 1.5 and consists of three sessions, during which the tool facilitates the achievement of various learning objectives [26]. Before the simulation, participants are educated about climate neutrality goals and energy communities. During the game, they gain knowledge about various energy efficiency measures, as well as the archetypes and characteristics of systems thinking that promote thoughtful decision-making and influence the attitudes and behaviors of other participants.

Table 1.5

Structure of the Simulation Game

0. General setting		Max 2 hours	6 participants	1 facilitator
1. Preparation			3. Follow-up	
Input for the simulation game		Learning objective 1: **knowledge about climate neutrality**	Q&A session	Feedback on the simulation game process
2. Execution		Simulation game Round 1	Simulation game Round 2	Simulation game Round 3
Introduction		Learning objective 2: **knowledge about systemic thinking**	Learning objective 5: **knowledge about multicriteria analysis**	Learning objective 8: **knowledge about creative solutions**
Game session		Learning objective 3: **knowledge about energy efficiency measures**	Learning objective 6: **knowledge about mastering the argumentation**	Learning objective 9: **knowledge about transformation theory**
Reflection phase	Evaluation	Feedback on Round 1	Feedback on round 2	Feedback on round 3
	Theory input	Learning objective 4: **Data analysis**	Learning objective 7: **Culture & behavior**	Learning objective 10: **knowledge about dashboards**
	Optimization	Alternative scenario	Alternative scenario	Alternative scenario

In each session, participants are provided with guidelines for their actions according to their assigned roles. The challenge for players lies in the specific individual goals and motivation for collaboration associated with each role (see Table 1.6). Information about the other roles is gradually disclosed to participants, simulating real-life situations where individuals operate with limited information. This approach encourages participants to communicate with each other to gain a broader understanding of the motivations behind other players' actions.

Table 1.6

Initial Priorities of Simulation Game Roles

#	Common goal: reduction of CO_2 emissions	Single senior	Nature activist	Farmer	Teacher	Plum-ber	Deputy
1.	**Each role's primary purpose for collaboration**						
1.1.	Saving energy	+	+	N	+	N	+
1.2.	Production of energy	N	+	N	+	N	+
1.3.	Sharing the resources	+	–	–	+	–	+
2.	**Primary motivation for each role to get involved (guaranteed benefits for municipalities)**						
2.1.	Construction of a sports field	–	N	N	N	+	N
2.2.	Repair of the open-air stage	+	+	+	+	N	+
2.3.	Greening of the territory	+	+	+	+	+	+
2.4.	Electric car connection	N	–	N	+	–	+

"+" – positive attitude; "–" – negative attitude; "N" – neutral attitude.

In the first session, participants make decisions with limited information. In the second session, participants are informed about the potential priorities of others but are unaware of any fundamental objections. If a participant makes a decision that infringes upon another’s core values, they lose benefits and the chance to speak in the final session, thus encouraging careful consideration of decisions. In the third session, participants are divided into three groups and tasked with choosing which opposing participants they would like to persuade to act in the community's interests, along with providing justification for their choices.

Participants are instructed to practice predefined behaviors and communication strategies suitable to their roles and to persuade other role-holders to act in alignment with shared interests, using various unconventional approaches and argumentation techniques. After each session, participants receive feedback on how their decisions impacted the overall game goal and discuss their actions, rationale, and consequences, reinforcing the learning objectives. The best decision-makers earn points recorded on a results table.

A barrier to collaboration is the challenge posed by cultural communication nuances. To simulate real-world conditions and enhance game dynamics, a general communication policy for players was developed within the study (see Fig. 1.5).

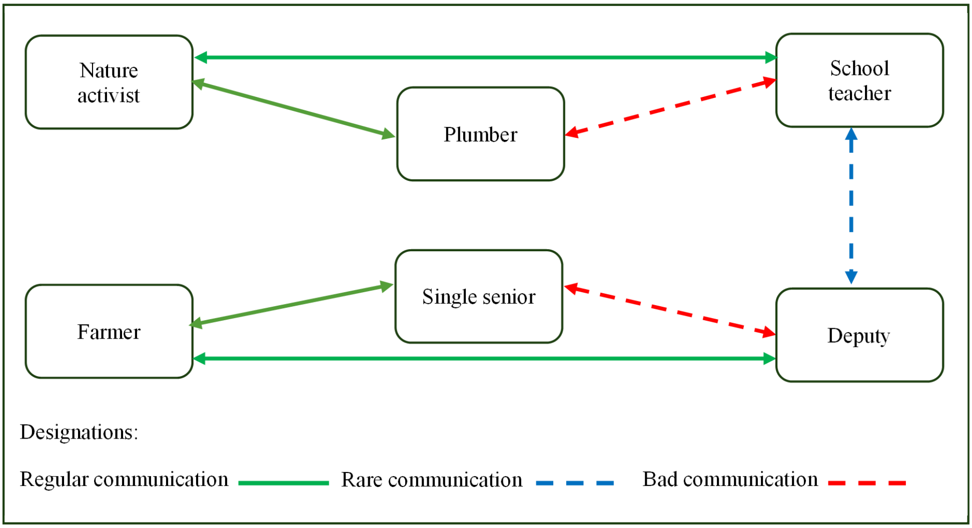

Fig. 1.5. Dynamics of interaction between roles in a simulation game.

Data obtained from sociological surveys and the system dynamics approach are utilized to develop various scenarios within the simulation game, incorporating individual behavioral characteristics and potential climate change mitigation measures. These scenarios enable participants to better understand their role in fostering successful collaboration, cultivate a more climate-responsible attitude, and encourage mutual cooperation in an environment with multiple participants who hold diverse attitudes and behaviors. After the simulation, participants are given the opportunity to discuss potential future decisions and their environmental impact, promoting a deeper understanding of consequences and a long-term perspective.

The Systems Thinking Workshop

The varying levels of public awareness, education, and understanding of responsible actions to mitigate climate change create demand for diverse educational methods. These tools, including interactive workshops, assist individuals in making optimal decisions as participants within complex social systems characterized by high uncertainty and numerous influencing factors. Critical thinking and skills in cause-and-effect analysis are essential for developing a climate-responsible society.

Within the study, systems thinking workshops are utilized as a third tool to practically validate the scientific aspects of the system dynamics model. These workshops aim to provide participants with a simplified insight into solving complex system problems, enhancing their ability to acquire, structure, analyze, and evaluate information necessary for deeper problem understanding and optimal decision-making.

The workshops last 3 hours and involve intensive interaction among participants, facilitating quick exchanges of decision drafts and their analysis from a systems thinking perspective. This approach helps reduce or prevent risks that may arise from specific future decisions. Participants are introduced to fundamental principles such as feedback loops, time delays, and nonlinear relationships to deepen their understanding of complex system dynamics. A detailed structure of the systems thinking workshop is provided in Table 1.7.

Table 1.7

Structure of the Systems Thinking Workshop

#	**Activity**	Time, min
1.	**Informing and educating participants** **Purpose:** To introduce participants to the basics of system dynamics using simple and easy-to-understand examples	
1.1.	Introductory lecture	20
1.1.1.	Introduction to the concept, archetypes and characteristics of systemic thinking. Practical examples from everyday life and work situations	
1.1.2.	Interactive presentations	
	Presentations use visualization tools such as PowerPoint with dynamic infographics to depict how systems work and their components	
1.1.3.	Use of graphs and charts	
	Examples of feedback loops, loop diagrams, and system maps are shown to illustrate complex systems	
1.2.	Interactive learning	40
	Participants are engaged in a discussion focused on past decisions and their consequences. An interactive quiz can be conducted to test participants' understanding of the basic principles of system dynamics	
2.	**Attitude and intention change** **Objective:** To promote participants' understanding of how systems thinking can help change their approach to problem-solving and decision-making	
2.1.	Group work and discussions	30
	Dividing the participants into teams of 3–4 people to discuss specific problems and apply the principles of system dynamics in the analysis of these problems	
2.2.	Review and discussion	30
	Presentations from each group on their findings and suggestions. Collective discussion about the discussed scenarios and their possible consequences	

Table 1.7 continued

3.	**A stimulating environment for action**	
3.1.	**Goal:** To create an environment where participants are motivated to apply the principles of system dynamics in practice and make informed decisions	20
	Solving problems based on practice and needs	
3.2.	Each participant chooses a problem arising from their needs in the context of climate change mitigation and proposes a way in which system dynamics can be successfully applied	
	Each participant puts forward an assumption – what real-time data needs to be used to promote optimal decision-making and create changes in the perception of surrounding individuals using visualization tools	
3.3.	Independent task	40
	Participants receive the task of developing and presenting short-term and long-term solutions to a specific problem, taking into account the archetypes and signs of system dynamics	
4.	**Conclusion and feedback** **Objective:** To summarize the results of the workshop, share key findings and offer resources for further education (simulation tools such as Stella Architect or Vensim). Participant feedback and suggestions for future improvements are obtained	10

In the workshops, systems thinking archetypes such as limits to growth, success to the successful, shifting the burden, drifting goals, tragedy of the commons, and others are introduced through examples and later applied. These archetypes help participants recognize the root causes of complex problems, identify recurring patterns, and develop sustainable solutions based on a systemic view of issues and their interconnections. The data gathered on the tool's effectiveness is used to analyze the impact of the workshops on participants' engagement and understanding of climate neutrality, as well as their ability to identify and potentially implement sustainable solutions. The results provide valuable insights into the effectiveness of the workshop as a method and its potential influence on individuals' understanding of climate change issues.

1.3. Methods of Interaction

Collaboration-oriented participation as an interaction method has become a recognized approach when working with target groups, as it fosters the involvement of a broader range of stakeholders in situation analysis and decision-making processes. This approach ensures more balanced efforts in establishing climate-neutral values, where the primary beneficiaries are the environment and society.

The blend of physical activity and gaming experiences, enabled by technological advancements, has also garnered research interest [27]. An interactive format that includes elements of co-design, co-creation, and co-production plays a crucial role in fostering user engagement [28].

Figure 1.6 illustrates the synergy of three essential elements – co-design, co-creation, and co-production – which contribute significantly to the development of a climate-responsible society [29].

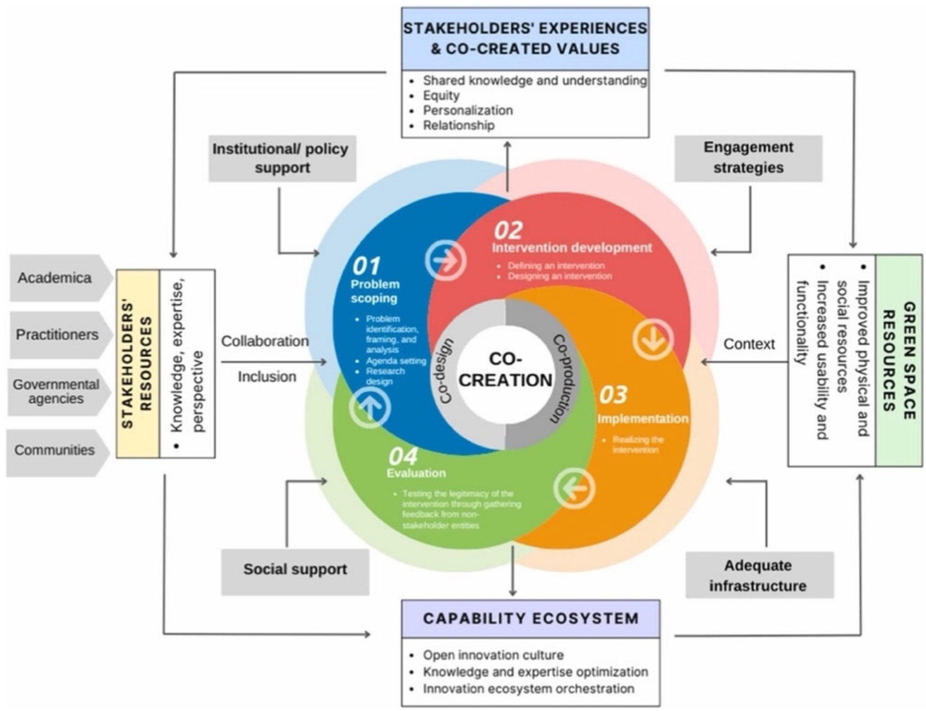

Fig. 1.6. An analytical framework for a systematic review of co-design, co-creation and co-production synergies.

Therefore, this study employs and further examines two methodological approaches – co-design (design thinking) and co-production (hackathon) methods. The integration of these approaches provides a foundation for effective interaction tools.

Design Thinking

Design thinking is a social technology that facilitates the emergence of teachable and scalable methods [30] and is used to address complex problems and drive interdisciplinary innovation [31]. Employed since the 1950s–60s, design thinking has been widely explored in academic literature and is positioned as (1) a methodology, (2) a way of thinking for designers, and (3) a practice-based approach.

As a methodological approach, design thinking spans a wide range in both engineering and social sciences [32], [33], [34]. In the past 20 years, it has become a prominent method for public engagement, significantly contributing to individual education and fostering critical thinking. Design thinking employs active learning strategies, such as group collaboration and hands-on learning, which enhance creativity in problem-solving [35]. Additionally, it can shape behavioral models and develop organizational culture, promoting digital transformation and innovation goals [36], [37]. However, the mechanisms through which organizations leverage design thinking to drive change and build capacity remain empirically underexplored [38], [39]. Design thinking, like qualitative research methods, opens new opportunities by combining the strengths of both areas to introduce effective innovations.

In this study, the design thinking method is applied based on the British Design Council's "Double Diamond" approach and the British Council's design thinking methodology, Future City Game, developed in 2006 by leading creative economy experts from the Centre for Local Economic Strategies in the UK. These methods are widely used to engage the public in urban planning and development issues but have not been extensively applied in the context of achieving climate neutrality goals.

Participants particularly highlight the game's value in acquiring new knowledge, improving decision-making processes, and enhancing interaction methods both within teams and between teams during the game. The game is organized over a 1–2 day period, with 30–40 participants divided into 6–8 teams. The Future City Game methodology includes ten steps (see Fig. 1.7) guiding participants from a deeper understanding of the context of the issues to practically tested and refined solutions.

Fig. 1.7. Ten steps of the design thinking methodology "Future city game".

The game methodology relies on extensive data analysis, teamwork and collaboration with external partners, exchange of ideas, a competitive voting element, idea generation, prioritization, presentation, and the gathering and analysis of feedback. The best ideas are tested in a real-world environment.

In this study, an enhanced process-oriented approach to design thinking is proposed – the *Future organization game*. This game is tailored for organizations in the public or commercial sectors, aiming to shift employee awareness, attitudes, and behavior patterns regarding the organization's environmental impact.

The existing tool structure is supplemented with discussions as a data collection method to assess participants' knowledge levels, attitudes, and behavioral changes. Qualitative data analysis allows for evaluating the effectiveness of the method across various educational aspects, such as the consequences and benefits of sustainable decision-making. This approach helps participants better understand human resource-related risks to the organization's sustainable development and the necessity for adaptive strategies. By identifying and analyzing organizational vulnerability factors, game participants learn how to better protect the organization and its infrastructure from the impacts of climate change.

Integrating these approaches into the *Future organization game* enhances its educational value, fostering a deeper understanding and engagement among participants in climate change mitigation.

Co-Production Method

In the scientific literature, hackathons are viewed as an interaction method in which participants with diverse backgrounds and expertise work together within a set timeframe, engaging in structured activities to create a joint initiative aimed at solving a specific problem in line with the thematic focus set by the event organizer [40], [41], [42], [43]. Participants share their knowledge, skills, and ideas to develop practical solutions, with significant emphasis placed on creating value through collaboration and open discussion. Hackathons can be organized as short-term events, lasting one or two days, or structured as long-term co-creation processes, extending over several weeks, depending on the organizer's goals.

The goal of developing a sustainability hackathon is to create a stimulating environment for individual action, enhancing understanding of climate change issues and fostering related solution development. This co-production format is suitable for systematic data collection and visualization, allowing participants to assess changes in their attitudes following the use of the tool.

While traditional hackathons are known for their problem "hacking" approach, they also promote community-based learning and interdisciplinary collaboration. This knowledge co-production format can provide institutional momentum [44], fostering cross-sectoral insights, building mutual trust, and strengthening relationships among participants over time [45]. Thus, hackathons become potentially effective active learning methods, providing a methodological foundation for deep, lasting, and meaningful learning that combines theory and practice.

The tool developed in this study is focused on engaging youth in addressing climate change issues through collaboration with the public sector (state or municipal institutions), as well as with the academic and commercial sectors. This approach can inspire young people to pursue environmental engineering as a future field of study or profession, providing them with opportunities to engage with science, research, and policymakers at a practical level.

The author's proposed improvements to the organizational structure of the sustainability hackathon (see Fig. 1.8) include not only data collection and analysis post-hackathon but also the integration of multiple elements to strengthen the tool's impact on climate-responsible awareness and actions.

These improvements include:

1) defining tasks and monitoring before and after the event;

2) diversifying forms of behavior that promote climate neutrality, such as resource sharing;
3) fostering participants' development as a community by maintaining social connections;
4) explaining and incorporating systems thinking concepts through informative materials.

Together, these elements enhance the sustainability hackathon's effectiveness, ensuring that it not only meets its objectives but also actively engages and inspires participants, promoting long-term climate-neutral behaviors and understanding.

To increase the appeal of this co-production method among youth, elements of game mechanics (such as obstacles, competition, roles, and points) are used, along with tasks drawn from the cultural and creative industries – visualizing team messages, challenging traditional assumptions, and other creative formats for presenting information or varying the process. These elements help mitigate the risk of diminished motivation during or after the hackathon.

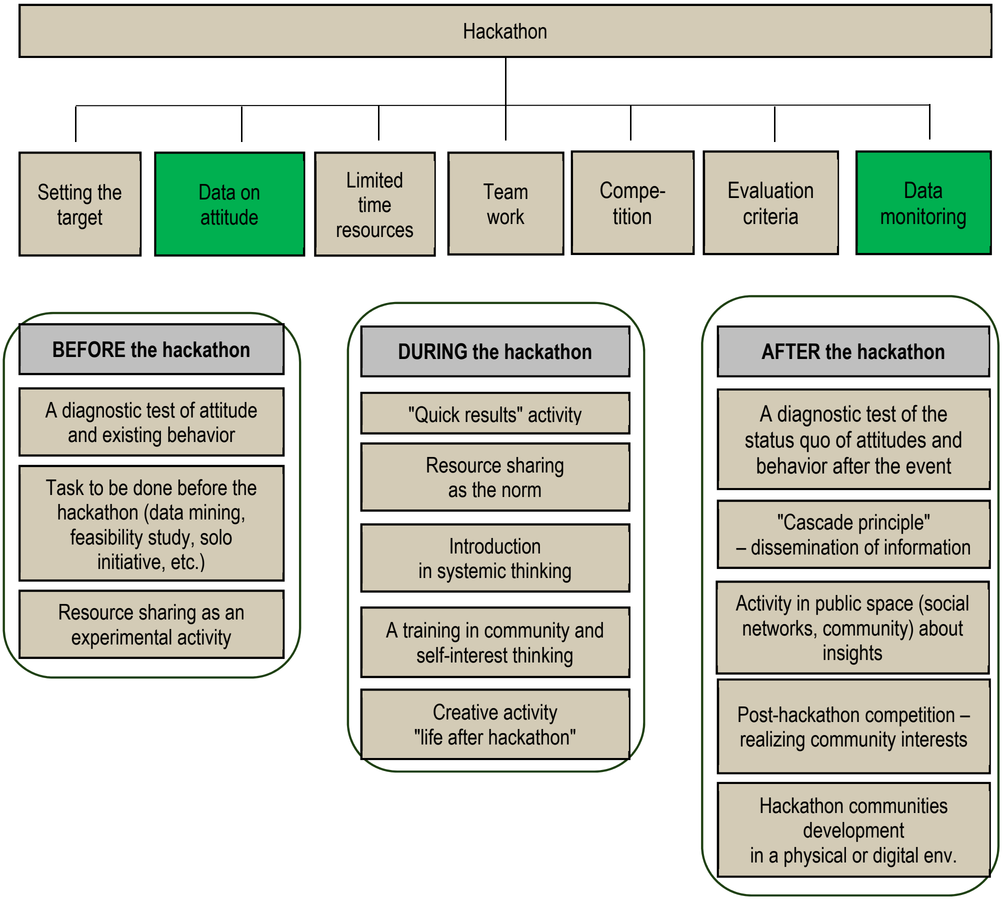

Fig. 1.8. Hackathon organizational structure.

As a result, the enhanced hackathon format provides an engaging atmosphere while motivating participants to continue their involvement beyond the event by participating in follow-up activities, such as surveys, feedback on the "cascade" principle adherence, post-hackathon competitions, and social media activities. This approach enables evaluation of changes in participants' attitudes and behaviors, as well as observation of a multiplier effect if participants carry out activities in their local communities or other target groups following their experience.

1.4. Bibliometric Method

The bibliometric method is widely used across various scientific research fields, relying on the analysis of academic publications' content and citations to identify the most popular topics, the impact of scientific works and their authors, and the development of research areas. This method is particularly useful when dealing with a large volume of publications related to a specific topic, as analyzing these manually would be time-consuming and inefficient without technological support. In fields with fewer than a few hundred studies, systematic reviews may be appropriate; however, for collections of 500 or more studies, bibliometric analysis is essential for more efficient handling [46].

The bibliometric method enables the assessment of the significance of scientific works, though challenges related to citation quality and the subjective evaluation of scientific contributions should be considered.

VOSviewer is a free software tool for creating and visualizing bibliometric networks, capable of processing large volumes of information to provide accessible and versatile analysis [47]. Developed by Nees Jan van Eck, a researcher at Leiden University in the Netherlands, it has become widely used for the visual mapping of scientific publications, including the processing of keywords found in these publications. Another commonly used tool in bibliometrics is CiteSpace. VOSviewer visualizations are more intuitive and user-friendly, while CiteSpace offers advantages in evaluative analysis of visualizations, such as cluster node analysis through the cluster browser [48], [49].

To ensure that the retrieved literature is closely related to this research and contributes to achieving the study's objectives, the following keyword combinations were entered in the Scopus search field under "Article title, Abstract, Keywords":

1) “climate” AND “society” AND “methodology” AND “behavior”;
2) “climate” AND “society” AND “behavior”;
3) “climate” AND “society” AND “attitude”;
4) “climate” AND “responsible” AND “society”;
5) “climate” AND “change” AND “mitigation” AND “attitude”.

The selection criteria for publications were limited to the following disciplinary categories: environmental sciences, social sciences, engineering, energy, psychology, arts and humanities, and decision-making.

The search was conducted on February 13, 2024, and the documents selected for analysis were those published in the Scopus database between 2014 and 2024 to ensure a focus on recent research. A dataset comprising 2,219 relevant articles was retrieved as the primary data source for this study.

1.5. Multi-Criteria Decision Analysis Method

One of the objectives of the Doctoral Thesis is to develop and evaluate a set of methods and measures suitable for working with diverse target groups. To achieve this, the methods developed within the study must be assessed as alternative solutions based on criteria of overall effectiveness and suitability. The quantitative and qualitative parameters of these criteria are defined by experts representing partner organizations, enabling the selection of methods aligned with one or more predefined goals.

The multi-criteria decision-making (MCDM) analysis method is a systematic approach that allows the evaluation and comparison of various decision options, considering multiple, and sometimes conflicting, criteria. This method was developed in 1981 by C. L. Hwang and K. P. Yoon [50] and is particularly useful in situations where various factors and trade-offs need to be weighed, such as time allocated for method application, resources required for implementation, target group size, and other criteria. The method is based on the assumption that the best solutions are those closest to the ideal solution and furthest from the worst solution.[51]

Given the need to apply a scientific approach beyond the academic setting, the TOPSIS TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method offers several advantages, such as the ability to use an unlimited number of criteria and alternatives, a relatively simple calculation process that does not require specialized software and results that allow for effective and transparent comparison of alternatives.

The process begins by identifying and defining criteria (C_1–C_7) that characterize the effectiveness and suitability of the tools for those implementing them:

1) informative and educational value – assesses how effectively the tool provides information and enhances participants' understanding of climate change issues;
2) demonstration of attitude and intent – evaluates the extent to which the tool enables individuals to express their views and listen to the perspectives of others;
3) creation of a stimulating environment – measures how effectively the tool allows individuals to actively implement their intentions during the method’s application or commit to action following the activity;
4) suitability for working with diverse target groups – assesses the method's adaptability to audiences with varied profiles and interests;
5) duration of simulation – determines the time resources required for implementing the method;
6) level of partner organization’s involvement – evaluates the human resource requirements for organizational tasks and the associated administrative burden;
7) audience reach – measures the number of participants who can simultaneously engage in the process provided by the method.

Evaluating these criteria enables the identification of the best opportunities to refine the methods developed within the study, ensuring their optimal adaptation to the needs of public or commercial sector organizations when working with target groups. This approach supports sustainable practices and promotes climate neutrality.

2. RESULTS AND DISCUSSION

This chapter compiles the results of the six scientific approaches described in Chapter 1, as applied across the five tools designed to promote the development of a climate-responsible society, which are illustrated in Fig. 2.

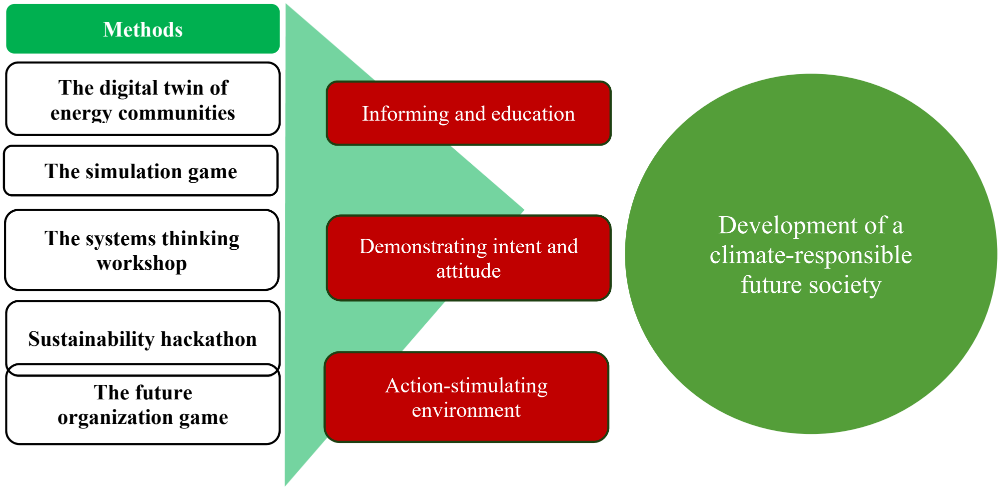

Fig. 2. The approved modules of the Thesis.

2.1. Results of Sociological Surveys

The purpose of conducting the two sociological surveys was to analyze the current energy efficiency practices and attitudes of Latvian residents towards climate change issues such as energy saving and production, environmentally friendly transportation, adoption of modern renewable energy resources, and the potential for creating energy communities among homeowners within the same or neighboring buildings. Additionally, the surveys aimed to identify potential opportunities to promote climate-responsible actions to be integrated into the developed interaction tools.

Both surveys used identical questionnaires and reached 1,005 respondents, though they involved different samples. The first survey was conducted in 2021, a time when there were no indications of potential war in Europe or rapid price increases. Consequently, in 2023, it was not possible to re-survey the same panel. Therefore, observations from the two surveys are not linked to unique respondents but provide insights into how attitudes have shifted. The data were weighted using national statistics on gender, ethnicity, age, and region as weighting parameters.

The 2021 study revealed that household energy efficiency measures rarely lead to the consistent adoption of more advanced energy efficiency practices. Data analysis of cascade decisions or sequential models in adopting energy efficiency measures provided limited evidence. Furthermore, understanding the causes of climate change did not increase people's willingness to invest in or change their behavior regarding climate issues. Environmental attitudes, reflected in practices such as energy saving or participation in environmental NGOs, proved crucial for adopting new technologies.

To estimate the prevalence of energy efficiency measures in Latvia, four main types of energy efficiency actions were examined. These included energy-saving practices at the household level, encompassing both electricity and heat-saving practices at the building level, with a focus on heating systems, energy production at the building level, and individual transportation habits. These types of measures and practices were selected to cover key prerequisites and future opportunities that households might consider when forming energy communities and developing future action plans.

The responses indicate that the most widely adopted energy efficiency measures occur at the household level (see Fig. 2.1).

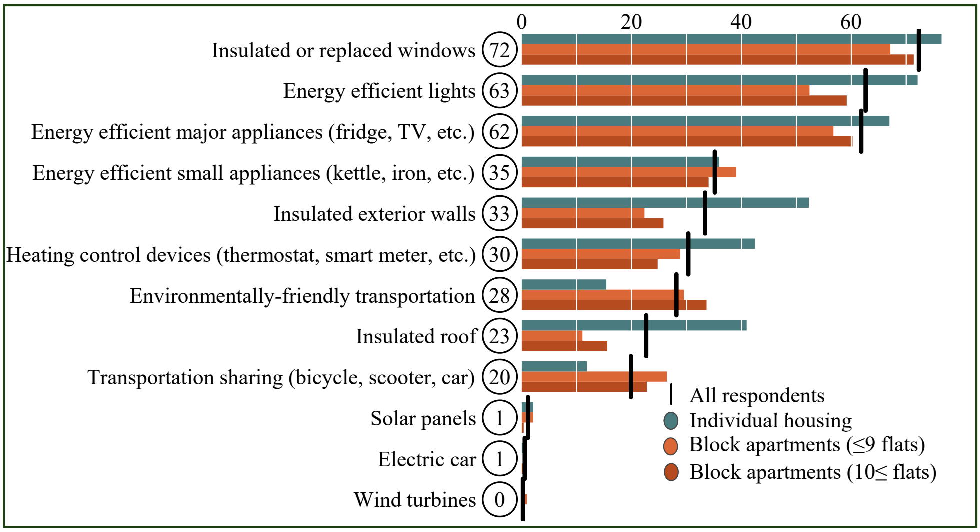

Fig. 2.1. Indicators of adoption of energy efficiency measures (in percent).

The majority of Latvian residents live in homes where windows have been insulated or replaced (72 %), energy-efficient lighting is used (63 %), and primary appliances are energy-efficient (rated at least A under the EU energy labeling, such as refrigerators and televisions, 62 %). In contrast, the adoption rates of measures that would require cooperation among multiple households – such as those in multi-apartment buildings or collaboration between households across multiple buildings for efficient energy blocks – are much lower.

The main differences in the pace of implementing energy efficiency measures across Latvian regions are related to transportation and mobility. Unsurprisingly, more people living in Riga – the only place in Latvia with a relatively high population density – tend to choose environmentally friendly mobility options, including public transport. Additionally, slightly more people in Riga, compared to other areas, regularly use shared transport options, which may be partially due to the greater availability of these options.

Survey respondents had the option for each energy efficiency measure to indicate whether they planned to implement it in the near future (within 2–3 years), in the more distant future, or did not plan to adopt it at all. They could also choose the option that it was difficult to provide a precise answer. Overall, the most common response regarding energy efficiency measures was the decision not to adopt them. Particularly for measures with low adoption rates, the majority of people who had not yet implemented a specific energy efficiency measure indicated that they did not plan to do so in the future (see Fig. 2.2).

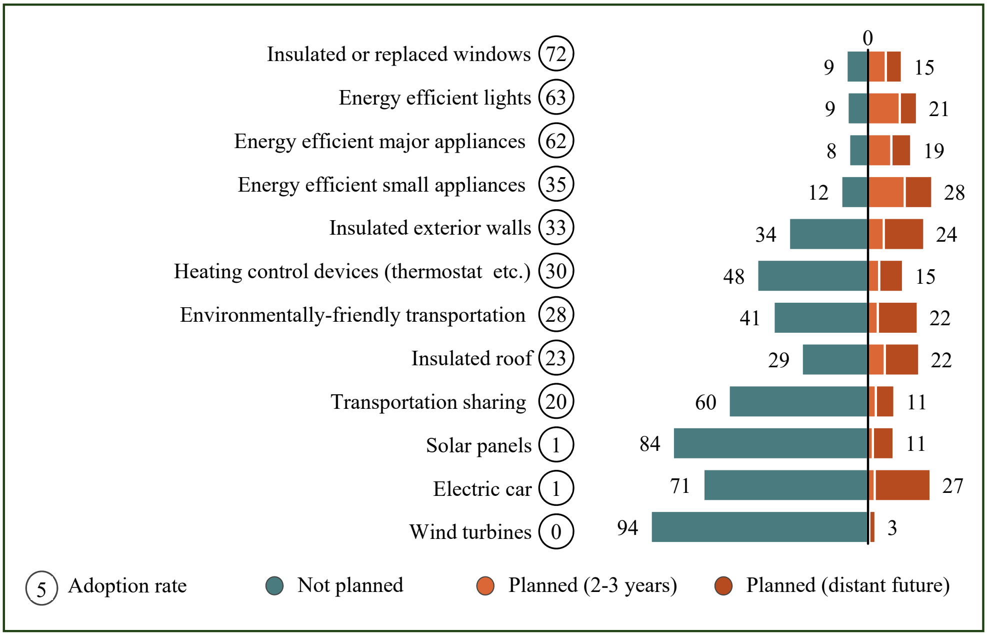

Fig. 2.2. Plans to adopt energy efficiency measures (in percent).

Comparing the plans of residents in apartment block neighborhoods with those living in individual homes reveals several key insights. First, the adoption rates for building-level heat-saving measures are higher among people who live in individual homes. Additionally, a relatively larger proportion of individual homeowners plan to implement these measures in the near future. For example, 32 % of individual home residents plan to insulate their roofs, compared to only 18 % of residents in buildings with at least ten apartments. Second, those considering becoming energy producers are typically individual homeowners. For instance, 29 % of individual home residents plan to install solar panels, while only 3 % of residents in multi-apartment buildings (with at least ten apartments) intend to do so.

Finally, responses from homeowners and their family members are very similar concerning plans for housing energy measures. The proportion of homeowners planning to take actions in this area exceeds the proportion among those who live in housing they do not own and are not related to the property owners.

Overall, it appears that people primarily evaluate energy efficiency measures in terms of private costs and benefits. They are also generally hesitant to rely on recommendations, especially when they come from public sector entities, such as municipalities or housing management organizations. While some consider expert recommendations to be important, there is variability in respondents' perceptions of who qualifies as an expert.

Survey results indicate that understanding of renewable energy resources in Latvia is relatively low, with 67 % of respondents reporting little or no understanding of these resources. This suggests a potential demand for more detailed information describing the social impact of each renewable energy source. Furthermore, incentives to act based on information about social costs could be enhanced through the introduction of a voluntary carbon market and the allocation of carbon credits to residents who choose to reduce carbon emissions. However, a drawback is that people in Latvia tend to prioritize private costs and benefits over social ones. Consequently, emphasizing social costs solely through voluntary private emissions reduction mechanisms may have a limited impact on national-level outcomes.

2.2. The Digital Twin of Energy Community

The system dynamics-based digital tool, "energy community digital twin," provided an interactive environment within the study that allowed participants to collaborate on optimizing energy consumption and resource management, thereby laying the groundwork for developing sustainable energy efficiency practices at the community level.

The testing aimed to assess both the tool's functionality and its impact on users' attitudes and decision-making. Initially, academic sector representatives with expertise in energy efficiency were chosen to test the simulation tool. Their feedback indicated the tool's potential for application in real-life household-level decision-making, as this group identified themselves as apartment owners making decisions about their properties' energy efficiency and market value. Twenty-nine participants took part in the testing, completing evaluation surveys to share their views on the tool's functionality and future applications.

The second primary target group was environmental engineering students, who positively assessed the tool in the context of making climate change mitigation decisions, thereby engaging with climate neutrality goals at a specific action level.

Following the initial testing within these groups, additional societal groups selected for the study included apartment building management companies, municipal development specialists, and youth. In total, 241 participants took part in 8 events, organized into six teams of 4–5 players each.

During the simulation, teams completed 4–9 runs, with the number depending on team dynamics and internal agreements facilitated by the tool's integrated chat feature. The primary task, set in the tool's initial parameters, was to reduce CO_2 levels. The largest reduction achieved was 80 % (from 604 tons to 123 tons) over nine runs, while the smallest reduction was 43 % (from 889 tons to 506 tons) across four runs (see Fig. 2.3).

Meanwhile, the total investment amount increased with each session, averaging from 1.2 million in Run 2 to 1.9 million in Run 4. The largest increase was 91 %, while the smallest was 25 %. One team made a choice that reduced the total investment amount by 40 % while still maintaining a positive trend in CO_2 emissions and cost reduction (see Fig. 2.4).

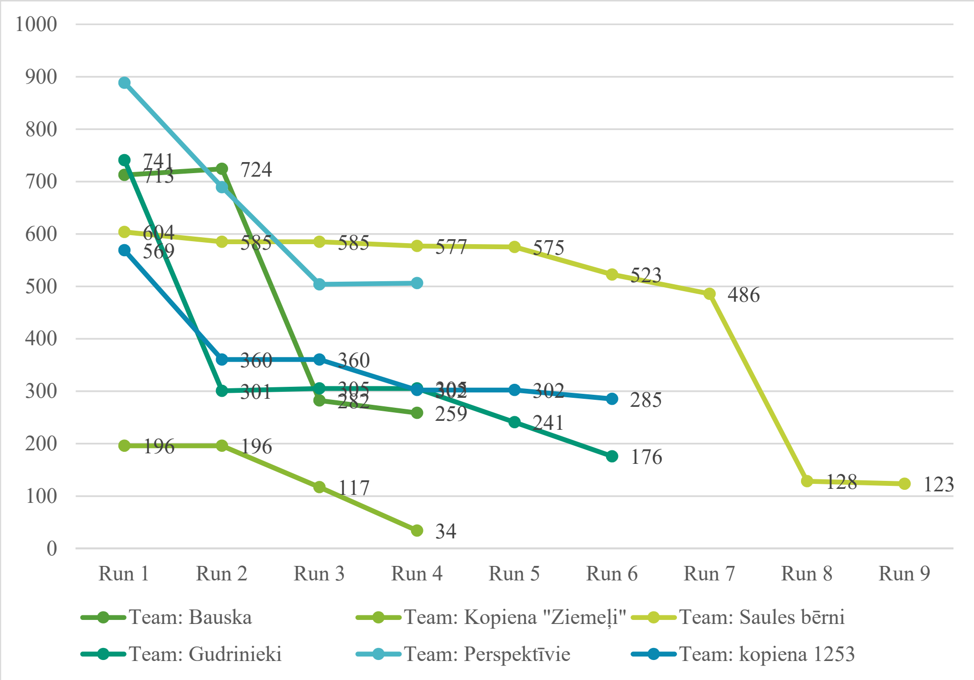

Fig. 2.3. Cumulative CO_2 emissions generated during the simulation, t/year.

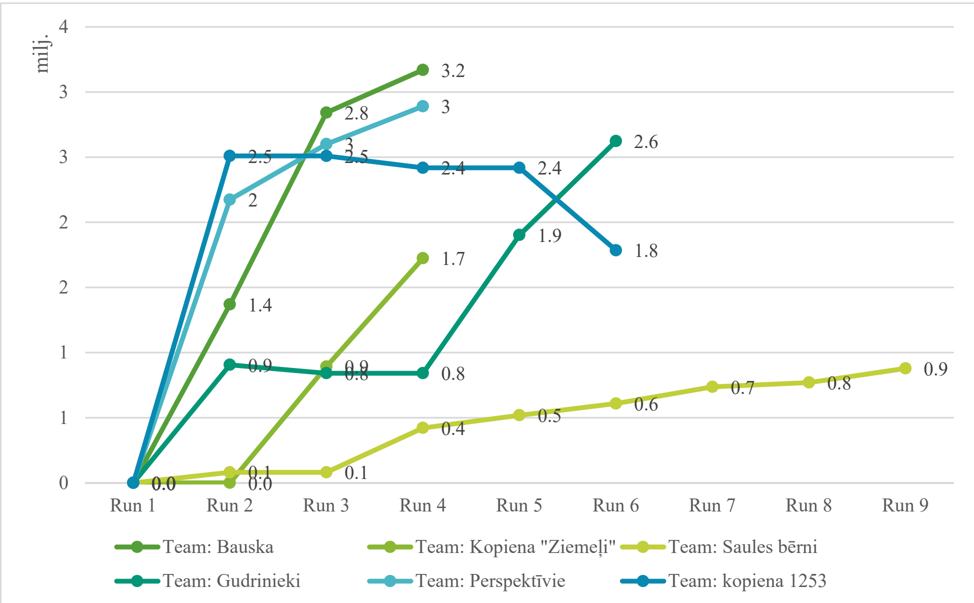

Fig. 2.4. Investments in energy efficiency measures during the simulation, EUR.

The simulation results of the digital twin suggest that the online tool supports participants in decision-making and collaboration, despite a complex set of parameters requiring focus on the outcomes of previous sessions. This tool allows users to experiment with their choices and view real-time results, and its interactivity promotes social learning in an environment where participants acquire new knowledge based on their actions.

The average payback period for investments was 5–6 years, with the highest being 11 years and the lowest 2 years by the end of the game. Three teams managed to complete the game with a payback period of 0 years – two teams achieved this in Run 9 and one team in Run 6 (see Fig. 2.5).

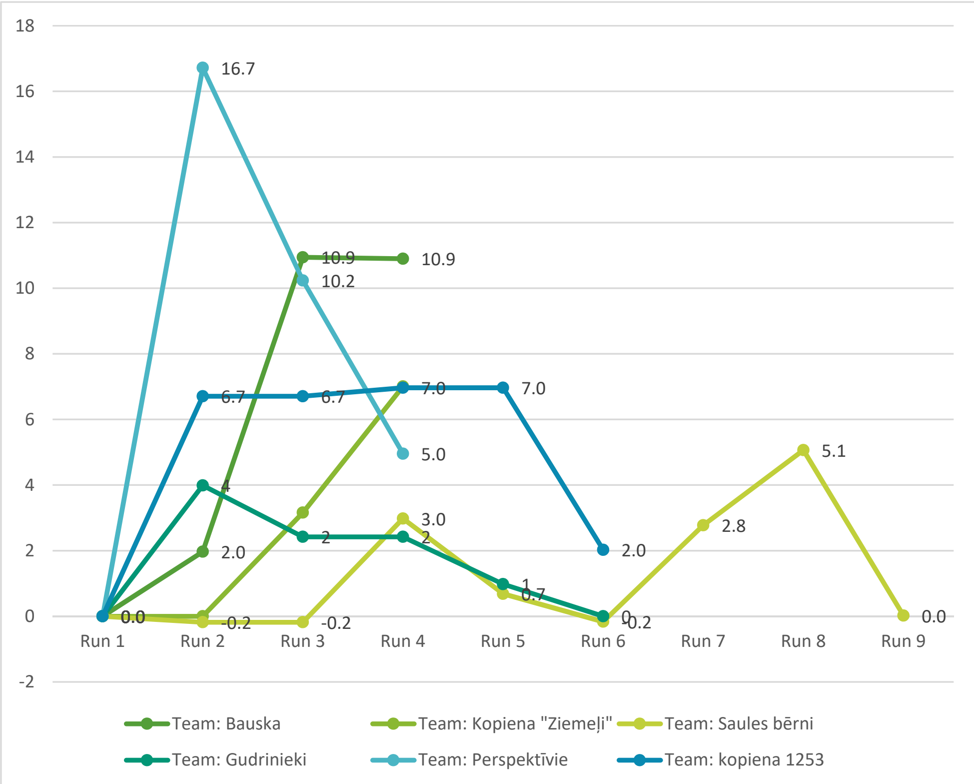

Fig. 2.5. Investment payback time during the simulation.

During the simulation, it was observed that the number of options within the tool to change habitual behaviors, such as lowering indoor temperatures, was relatively limited. The indicated room temperature ranged from 18 degrees to 24 degrees Celsius, reflecting players' low willingness to reduce daily comfort levels, preferring instead to implement other energy efficiency measures, despite being aware that lowering temperature could reduce energy consumption (see Fig. 2.6). This provides valuable insights for the author regarding aspects to integrate into other interaction tools to promote discussion and collaboration for improving energy efficiency practices.

In the final run, one team agreed to lower the temperature by 1–2 degrees. One participant made this change in Run 5, reducing by one degree, and in the last run, three additional players made similar adjustments, resulting in a decrease in the average temperature compared to the initial choices. Overall, players across all teams reduced the temperature by 27.5 % through their choices.

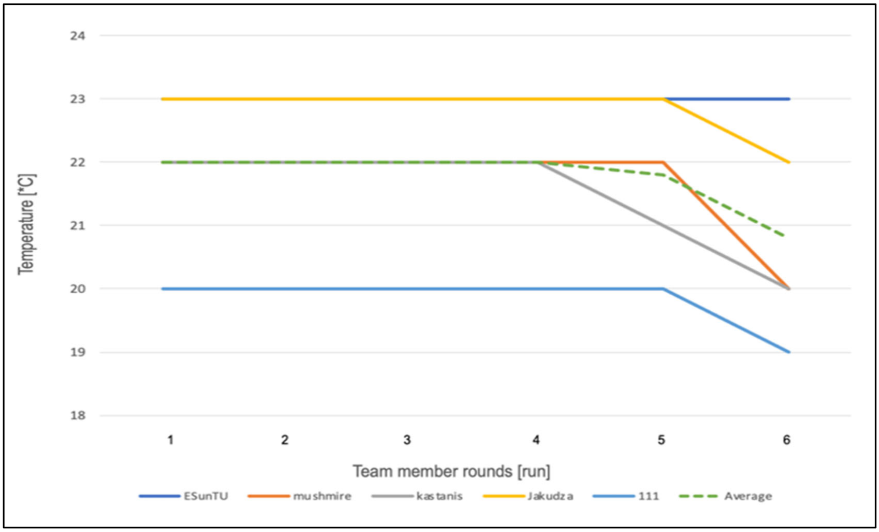

Fig. 2.6. The case of the team's decision to lower the temperature.

The simulation results indicate that players adjusted their decisions based on an agreement to achieve a shared goal (e.g., CO_2 reduction) and that in subsequent sessions, players demonstrated a willingness to collaborate for collective interests.

Overall, 81 % of participants in the online survey positively evaluated the tool as a method for gaining information and fostering collaboration, while the remaining respondents noted that the game-like, competitive format prevented them from perceiving it as applicable in real conditions. However, some indicated they might view it more positively if they could trust the reliability of the processed data. Regarding the clarity of calculations provided, 48 % responded affirmatively, 18 % negatively, and some indicated they did not delve into the calculation explanations. Similar responses were given regarding the perceived reliability of the calculations.

Furthermore, 55 % affirmed that the audiovisual guidelines were sufficiently comprehensive for tool usage, 16 % admitted to not fully engaging with the guidelines, while the remainder suggested improvements, such as providing explanations more slowly and including additional resources to better understand specific terms.

Target groups were asked to indicate the primary application of the tool (see Fig. 2.7). The results show that municipal representatives are most likely to use the method to persuade their target groups, while nearly a third of youth indicated they would not use the tool. According to the author, given the tool's specific relevance to agreements on energy efficiency measures, it is likely less relevant to young people, as they are generally not responsible for building energy efficiency improvements or utility payments in their daily lives.

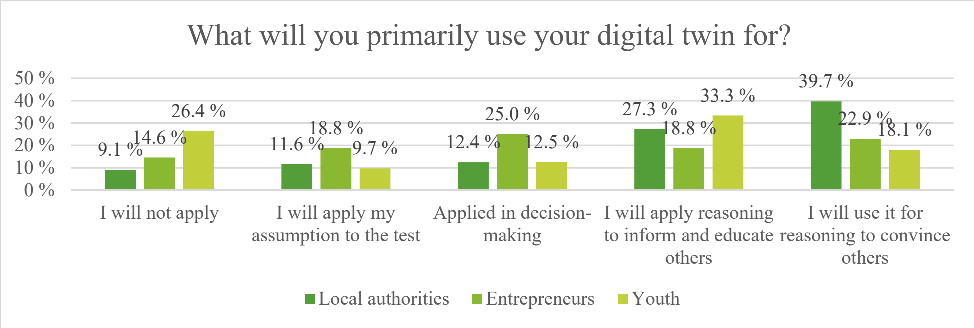

Fig. 2.7. Responses of the target groups on the primary use of the tool.

Entrepreneurs rated the tool's applicability for decision-making most highly (25 %), indicating that this target group finds digital solutions useful for strategic planning, especially those that enable optimal, data-driven decisions. Implementing such tools can enhance this group's ability to apply digitalization processes to incorporate sustainability principles in their organizations, involving personnel in the process. When asked whether this tool could potentially help residents of neighborhood apartment buildings make optimal decisions, 41 % responded affirmatively, 19 % rejected the idea, and the remaining considerations were related to players' individual interests (such as the fiscal impact on household budgets) and the need for trackable data on the outcomes of decisions throughout the simulation.

Regarding factors most likely to influence the target group's willingness to use the digital twin for decision-making (see Fig. 2.8), municipal representatives highlighted the importance of the visualization function for working with their target audiences, while entrepreneurs prioritized information accuracy, and young people valued the opportunity to observe the results of collective efforts in CO_2 emissions reduction.

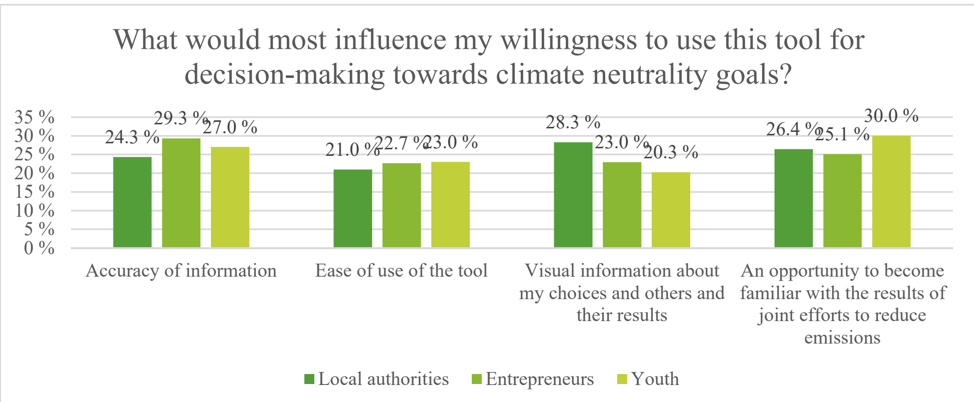

Fig. 2.8. Responses of the target groups on factors influencing the use of the tool.

The results indicate that players would exhibit different behavior if they did not receive information after each run about other players' choices and their impact on achieving the common goal.

The proposed tool was tested and validated through events organized by the Institute of Energy Systems and Environment at Riga Technical University, Rīgas Namu Pārvaldnieks, Liepājas Namu Apsaimniekotājs, and the Vidzeme Planning Region. These events aimed to enhance energy literacy among residents of multi-apartment buildings and foster the development of energy communities.

2.3. The Simulation Game

As an analog format corresponding to the digital tool described in Section 3.2, a simulation game was developed within this study. The need for this format arises from varying levels of digital skills across different societal groups, which limits the comprehensive application of digital tools for achieving the study's objectives. To enhance the effectiveness of role-playing games as a format for promoting climate-responsible actions within the target group, the content was informed by bibliometric analysis results, incorporating the latest trends and climate-responsible behavior concepts mentioned in relevant publications.

Figure 2.9 illustrates the connection between scientific articles containing the terms "climate change" and "attitude" (articles selected from 2014 onwards). A total of 2,219 articles were indexed in the Scopus database, with a minimum word recurrence frequency in the figure set at ten occurrences.

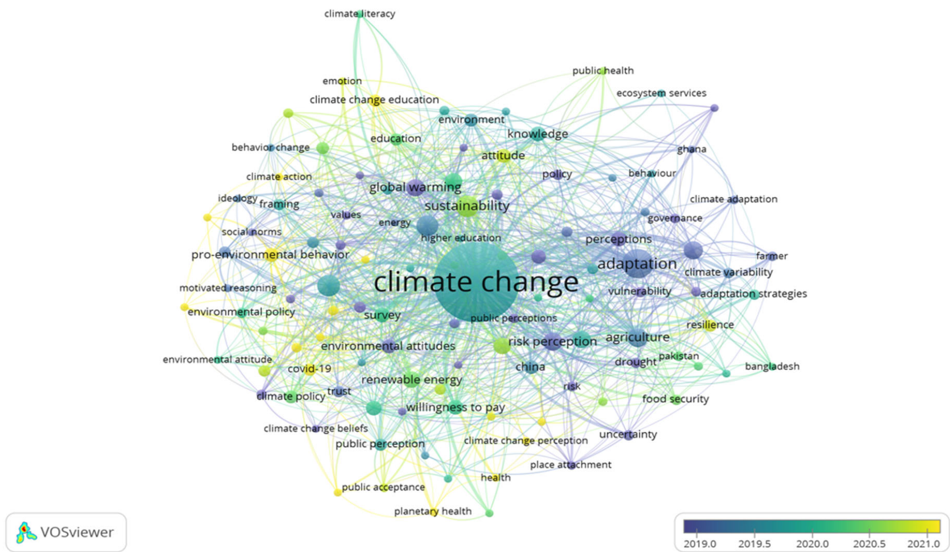

Fig. 2.9. Chronological visualization of the bibliography with the combination of the words "climate change" and "attitude" since 2014 (minimum frequency of word repetition – 10 times).

In developing the content of the simulation game, terms associated with "attitude" – such as "assumptions," "knowledge," "social acceptance," "social norms," "trust," "public opinion," "research," "behavior," "education," and "risk perception" – were incorporated, as the author believes these contribute to transforming complex social systems. These terms were used within the simulation game.

During the simulation, nearly all participants positively evaluated the knowledge they received before and after the session, enhancing their understanding of both the impact of building a climate-responsible society on future community quality of life and how each individual can participate in climate change mitigation efforts (see Fig. 2.10).

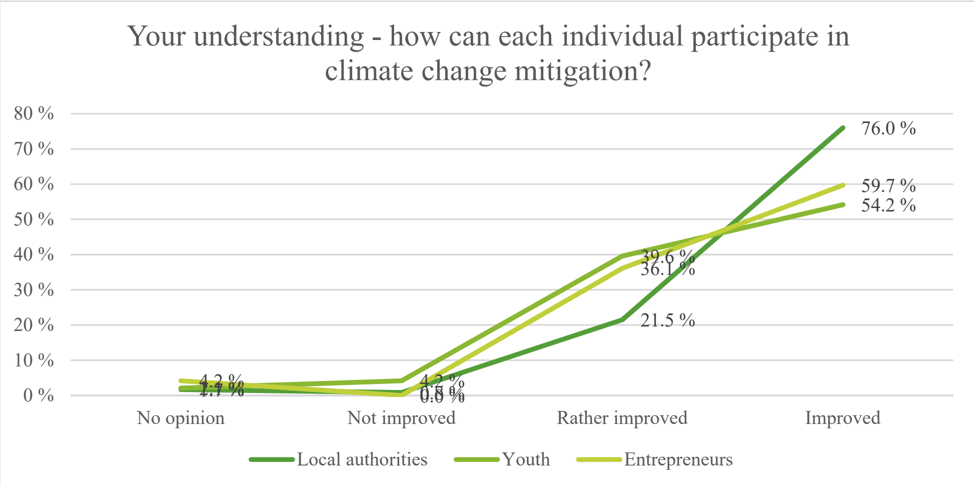

Fig. 2.10. Evaluation of target groups on the understanding of the possibilities of involvement in mitigating climate change.

The presence of diverse social roles enabled the simulation of real-life situations where people with different experiences and perspectives must find the best solution to a problem. According to participant feedback, the need to collaborate in an environment with diverse interests encouraged them to reassess their self-centered interests and to prioritize collective interests, fostering a sense of responsibility for the future quality of life for themselves and others (see Fig. 2.11).

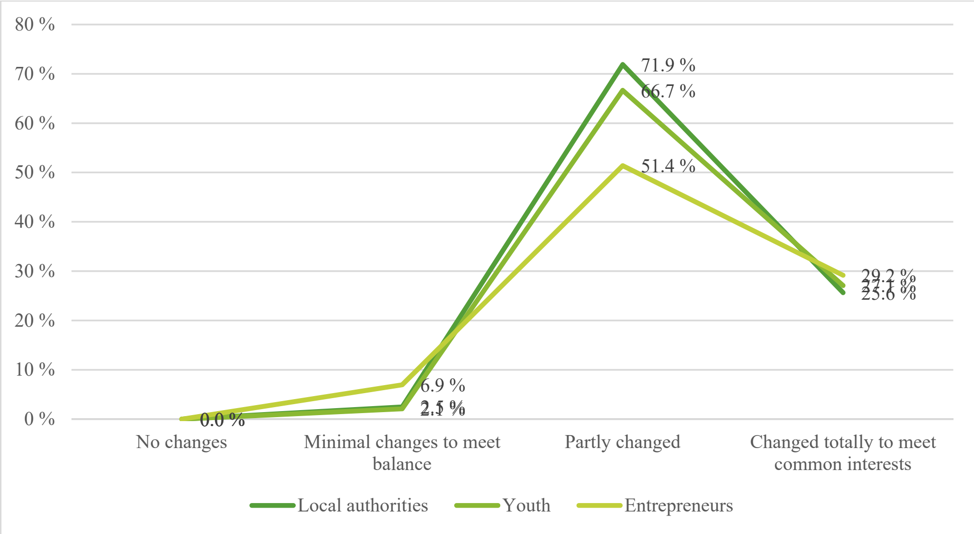

Fig. 2.11. Revaluing the individual interests of target groups in the name of collective interests.

The study identified the following factors influencing players' behavior and decisions (see Fig. 2.12):

a) awareness of the urgency of climate change – participants could assess the severity of the situation and familiarize themselves with a variety of available tools;

b) rapid technological advancements make resource sharing more feasible – breaking down physical barriers and uniting around shared values;

c) application of multi-criteria decision-making analysis – in analog simulation games, where complex calculations are unavailable in real-time, this analysis aids in making prompt decisions and provides a rationale for choices;

d) provision of systems thinking as introductory information at the start of the simulation game – this enables participants to understand the significance of their attitudes, decisions, and behaviors in the community transformation process.

Participants also appreciated the accessibility of simulation games for people with varying levels of digital skills, ensuring that no societal groups are excluded from engagement and learning opportunities. Municipal employees noted a potential demand for similarly practical, easily adaptable tools of varying complexity levels.

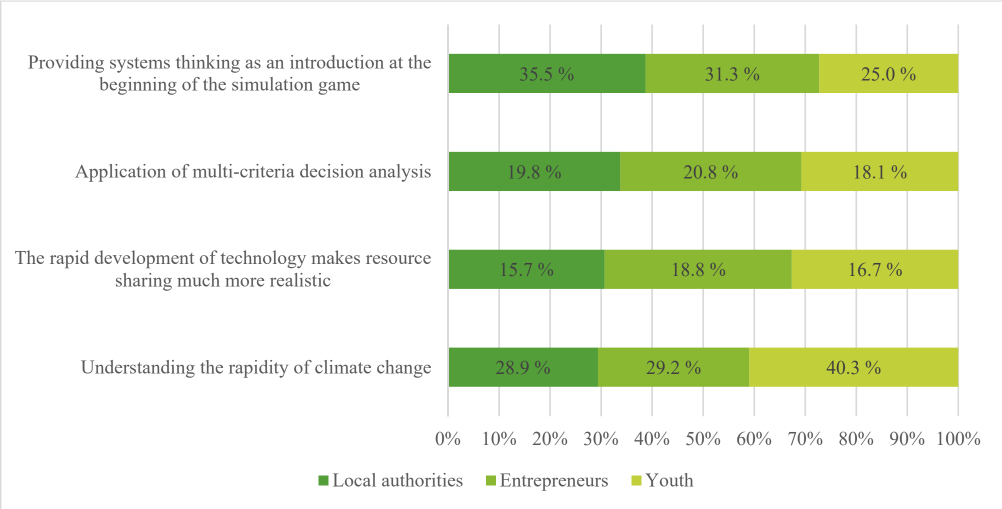

Fig. 2.12. Evaluation of the target groups on the factors that influenced their attitude during the game.

The method was validated at events organized by the Latvian National Centre for Culture, Rēzekne Municipality, and the Southern Latgale NGO Support Center, focusing on sustainable solutions for diversifying cultural activities and developing civil society.

2.4. The Sustainability Hackathon

The task for student workgroups was to develop a business plan for recycling a problematic type of waste. This process included situation analysis, exploration and evaluation of alternative and technological solutions, economic justification, and identification of potential intellectual property rights.

The diversity within the teams allowed for the simulation of real-life situations where people with varied life experiences and perspectives need to find an optimal solution to a problem. According to participant feedback, the need to collaborate in a highly competitive environment among teams encouraged them to take initiative in complex situations, feel responsible, and commit to their roles. Such experiences have a positive impact on individual character, allowing participants to open up and understand their own capabilities and potential.

As an educational activity within the hackathon, teams tackled the following hard-to-recycle waste types:

a) waste-derived fuel – solid household waste processed into a uniform fuel mass, which can be used as supplementary fuel for energy generation in thermal power plants or burned in special facilities for energy production;
b) used tires – exploring options for economically viable recycling technologies;
c) fiberglass – a type of waste regularly brought to a hackathon participant's landfill, allowing the company to anticipate demand for processing services.

The hackathon enabled students to effectively and visually grasp educational content focused on environmental innovation. The method's content included elements essential for developing competencies needed for the competitiveness of new professionals in environmental sciences.

The event consisted of three stages, each dedicated to one of the three waste types, with three teams participating in each stage. Based on the results achieved, an expert jury selected a finalist, who was then allowed by the company to participate in a broader hackathon. In the course of the study, three hackathons were conducted, with a total of 71 participants learning about system dynamics principles and various approaches to solving complex system problems. This experience allowed participants to analyze system structures and gain a deeper understanding of the causes of system behavior, enhancing their ability to address problematic behaviors [52]. The observed results within the conducted study [53] indicate that people in Latvia's regions are aware of energy efficiency measures and provide insights into the diversity of experiences gained.

The question, "Would you be willing to live in cooler rooms (2–3 degrees lower room temperature) to reduce CO_2 emissions?" highlights the challenges associated with changing habits, even among the younger generation, who are generally considered more active and willing to engage in environmental issues. More than half (58 %) of respondents indicated they were not willing to lower the room temperature in their homes to achieve climate neutrality goals (see Table 2.1).

Table 2.1

The Most Frequently Mentioned Energy Efficiency Measures from the Perspective of Young People

#	**Question**	**Yes (%)**	**No (%)**
1.	Would you be willing to live in less warm spaces (within minus 2–3 degrees) to reduce CO_2 emissions?	42	58
2.	Do you know what is the amount of utility costs per month in your household	56	44
3.	Can residents of the same building be both energy consumers and producers?	91	9
4.	Or discuss energy saving measures in your home with your loved ones	58	42
5.	Do you think you could influence the energy consumption habits of your loved ones?	60	40

These responses prompted a closer examination of the respondent group, as a clear understanding of the motivations behind decisions and actions is essential for developing a climate-responsible society. The discussion highlighted three typical reasons for the high proportion of young people unwilling to accept a lower room temperature. First, this is influenced by the attitudes and behaviors of their family members. Second, young people are generally not responsible for paying utility bills, so they may not fully grasp the financial burden. Third, similar to adults, young people experience a social dilemma – self-interest related to household comfort outweighs societal interests in contributing to climate change mitigation.

One of the concluding topics of the discussion was the motivation of young people to engage in climate-responsible activities (e.g., energy saving and production, shared transportation). Responses to this question highlight the presence of a social dilemma among young people – their motivation to participate in climate-responsible actions is higher when these actions align with self-interest, such as improving future quality of life and reducing utility costs (see Fig. 2.13).

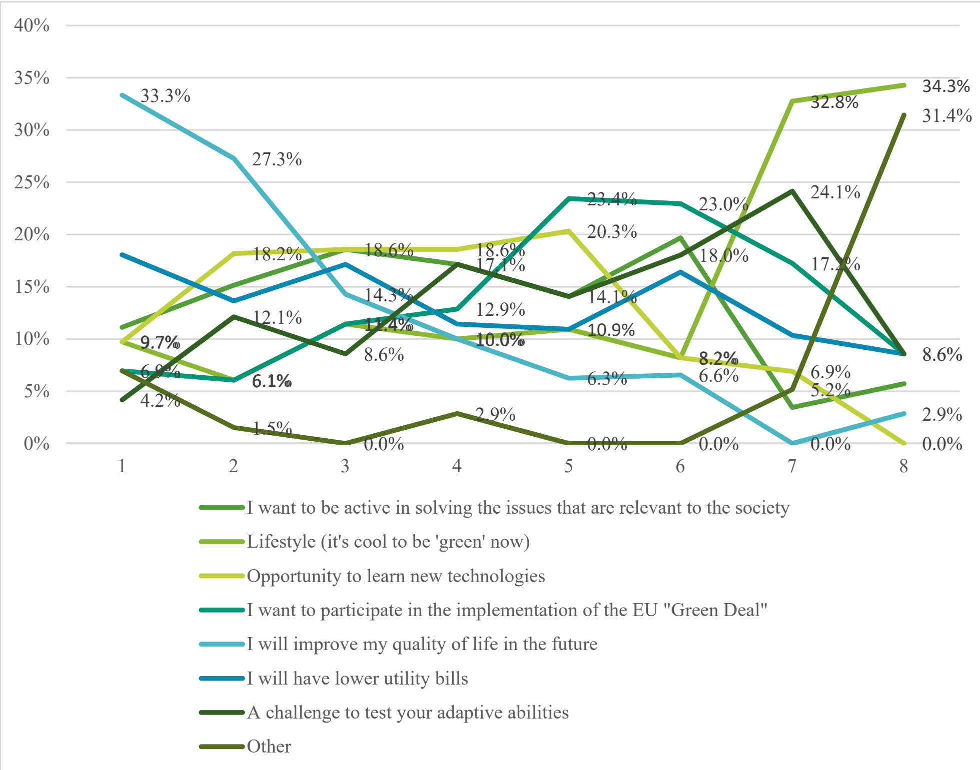

Fig. 2.13. Respondents' motivation to engage in climate-responsible activities.

To enhance their ability to select the best ideas, participants learned a simplified version of the multi-criteria decision-making analysis method. Together, they established criteria for evaluating ideas and assigned weights to each criterion in collaboration with qualified mentors. This approach enabled the teams to assess a wide variety of ideas and filter out meaningful actions to achieve optimal results. An example of an initial evaluation matrix from one team's idea assessment is shown in Table 2.2.

A similar process was followed to select the best idea during the hackathon: by evaluating all team contributions, each team chose the optimal idea to which points were awarded in a final team vote. Although this was not a comprehensive approach due to time and technology constraints, teams were introduced to the free online application of the TOPSIS method to facilitate learning, enabling them to use this method for research purposes beyond the hackathon.

Table 2.2

Application of the MCDA Method (Example) in the Evaluation of ideas

Criteria/ Ideas	Evaluation scale (1-5)	Weight	Cinetic floor	Intellec-tual box	Eco energ y	Open-air energy	ERZ	Saers	Kitchen of emotions	Journey to the Sun
Towards a climate-neutral solution	1-5	0,2	1,0	0,6	0,4	1,0	0,8	0,6	1,0	0,6
Quality of feasibility study	1-5	0,2	0,4	0,8	0,6	0,4	1,0	0,4	1,0	0,4
Identifiable type of innovation	1-5	0,15	0,8	0,8	0,5	0,8	0,3	0,2	0,3	0,3
Quality of business model	1-5	0,1	0,2	0,1	0,4	0,5	0,3	0,1	0,5	0,2
Technology readiness level	1-5	0,1	0,5	0,5	0,3	0,5	0,3	0,4	0,5	0,4
Level of innovation (local, regional, global)	1-5	0,1	0,5	0,5	0,1	0,5	0,1	0,1	0,5	0,1
Contribution to one or more of the UN sustainable development goals	1-5	0,05	0,3	0,2	0,3	0,3	0,3	0,2	0,3	0,1
Team performance	1-5	0,05	0,3	0,3	0,3	0,3	0,1	0,2	0,3	0,1
Participants have articulated their role in implementing the solution	1-5	0,05	0,1	0,3	0,2	0,3	0,1	0,2	0,3	0,1
Total			3,95	3,9	2,95	4,4	3,25	2,35	4,55	2,3

The belief that visualization can significantly aid in persuading others has grown the most rapidly. During the hackathon, teams prototyped their ideas and presented them to the other teams in a final demonstration aimed at winning the competition (see Fig. 2.14).

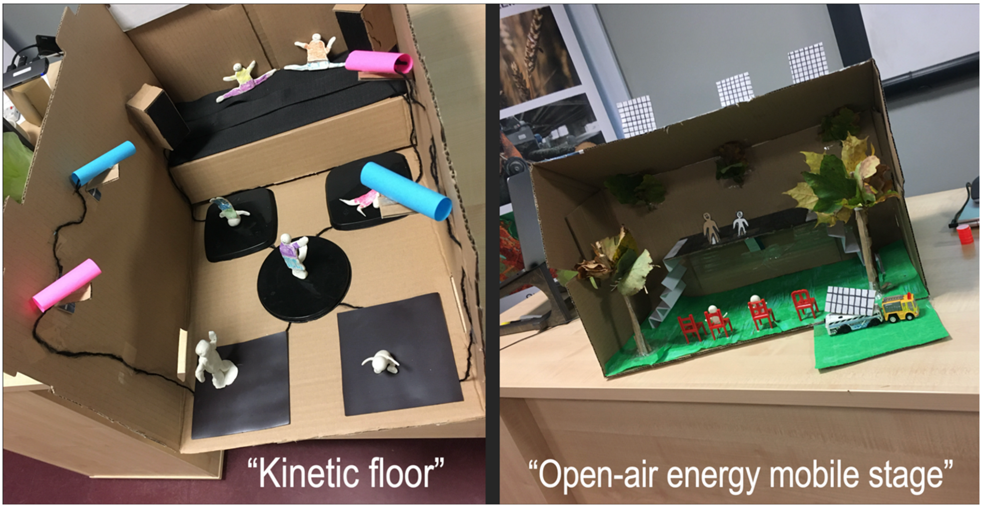

Fig. 2.14. Prototypes created by teams to visualize ideas.

The method was validated at events organized by the Vidzeme Planning Region and the Social Entrepreneurship Association of Latvia, focused on strengthening human resource capacity and promoting sustainable solutions in public governance, community, and entrepreneurship.

2.5. The Future organization game

To obtain and reflect results, 14 Future organization games were organized, focusing on staff engagement in sustainability topics related to energy efficiency, organizational culture, work environment improvement, human resource development, and digitalization promotion. A total of 418 participants took part, representing the target groups defined in the study from all planning regions of Latvia – 209 municipal employees (development specialists and those working in culture, youth, and education), 84 young people representing youth centers, and 125 private sector representatives from various industries, including ICT, waste management, financial services, and healthcare.

During the game, participants were divided into teams of 4–5 players, based on profile diversity and played through 10 stages – from identifying needs to testing proposed solutions within their teams in real environments, culminating in presenting their results to the other participants.

The achieved results (see Fig. 2.15) indicate that game participants were able to meaningfully apply the knowledge they gained to reach individual or team goals within the game context.

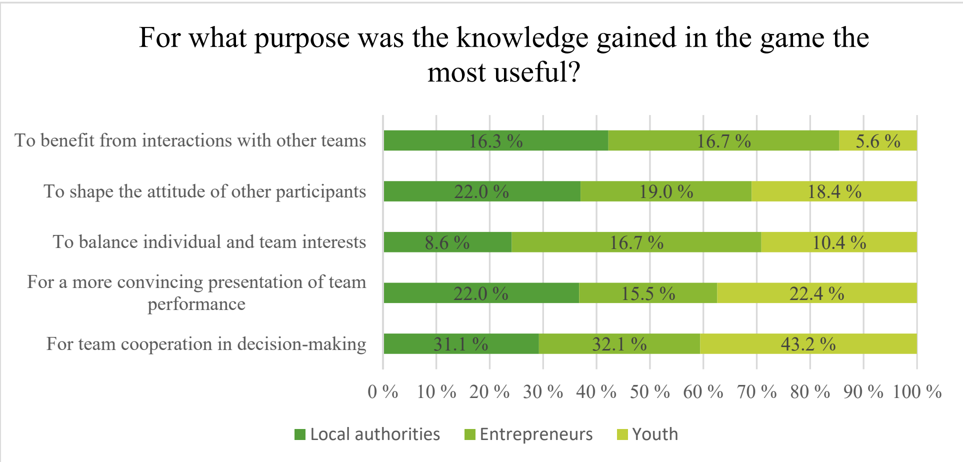

Fig. 2.15. Application of acquired knowledge in the evaluation of target groups.

All target groups rated teamwork in decision-making most highly – this, according to the author, was facilitated by the inclusion of the multi-criteria decision-making analysis method in the game methodology. Participants valued the opportunity to acquire practical skills that could be applied in the future, enhancing the tool's potential impact on fostering more considered decision-making in society.

Municipal representatives and entrepreneurs rated the knowledge gained from interacting with other teams moderately high (16 % and 17 %, respectively), enabled by the team sparring activity included in the game, where teams provided feedback on each other's ideas, highlighting potential risks. In contrast, young people rated this activity relatively low (6 %) –

likely due to a lack of communication skills or an inability to see the value of sparring as an activity.

By using tools offered in the Future organization game (idea visualization on posters and the option to role-play scenes to illustrate outcomes), participants confirmed (with an average rating across all target groups of 83 %) the author's assumption that visualization is an influential tool in shaping other participants' attitudes and positions on sustainability issues.

To assess the game's impact on participants' attitudes and intentions in the short term, a concluding discussion was held. In this session, the more sceptical participants revealed that, upon seeing visual information on the progress of change, they reconsidered their attitudes and expressed a willingness to balance individual and collective interests. Participants acknowledged that the immediate aggregation and display of results influenced their attitudes and behaviors more quickly than if this relevant information had been unavailable. Some players noted that the risk of being seen as the only ones prioritizing personal interests over collective interests motivated them to change their actions.

Using the free online software at OnlineOutput.com, participants learned to use the TOPSIS method to model the optimal work mode for their organization, considering climate neutrality and productivity factors. Participants established criteria and, with the involvement of management representatives, assigned weights to each. Before this, they exchanged arguments, conducted a vote, and later compared the vote results with those generated by the TOPSIS method. Table 2.3 and Figure 2.16 illustrate the application of the TOPSIS method within the team – from defining alternatives and criteria to determining the best alternative.

Table 2.3

Step 3: Evaluation of criteria

	Emissions	Waste	Socializing	Productivity
Office work	5	5	5	3
Remote work	1	3	2	4
Hybrid format	3	4	4	4

The results sparked an active discussion among participants about decision-making methods and processes and how objective they are in situations where (a) decisions are left to a single individual, (b) not all possible alternatives are considered, and (c) there is no information on the varying impacts of different criteria. The application of the TOPSIS method offered much broader opportunities for collective involvement in making decisions crucial for organizational sustainability, considering collective interests and reducing subjective approaches to achieving shared goals.

Feedback indicated that in situations with seemingly incomparable impact factors in decision-making (as in the example provided – productivity versus progress toward climate neutrality), the TOPSIS method serves as a qualitative, transparent, and time-efficient tool. This method could become a valuable instrument for fostering organizational culture.

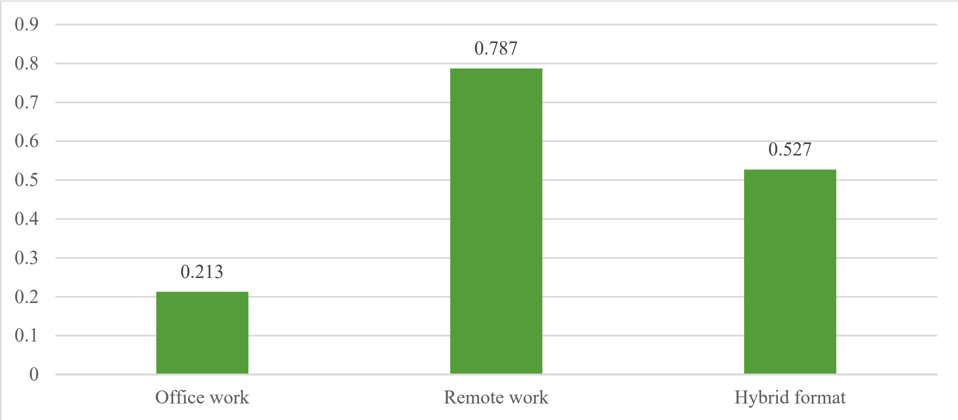

Fig. 2.16. Step 8: Closeness to ideal and ranking of each alternative.

Additionally, participants noted that using the TOPSIS method motivated them to seek more objective, data-driven information, evaluate criteria application more critically, involve the collective horizontally and vertically in assigning weights to criteria, and foster a stronger desire to make more considered decisions, encouraging the same among colleagues.

The method was validated at events organized by the European Digital Innovation Hub, Vidzeme Planning Region, Zemgale Planning Region, Latgale Planning Region, Rīga Planning Region, Daugavpils City Municipality, Līvāni Municipality Council and Talsi Municipality, all focused on strengthening human resource capacity and organizational culture within the context of sustainable solutions.

2.6. The Systems Thinking Workshop

To gather and reflect results, 7 systems thinking workshops were organized for municipal employees in development, culture, and youth affairs, as well as for an audience of entrepreneurs, with a total of 132 participants. Initially, youth were also selected as a target group; however, based on feedback from the first session, the author concluded that limited experience hindered younger participants' ability to grasp the nuances of systems thinking features and archetypes, which required more explanation and significantly extended the workshop duration. The author suggests that future studies could explore how to adapt systems thinking content to leverage young people's existing experiences.

Overall, nearly all respondents (93 %) acknowledged that the knowledge and skills gained in the systems thinking workshop are practically applicable for reconciling short- and long-term interests, and they expressed motivation to apply this approach in future decision-making based on community interests and benefits. Although 73 % indicated that deeper understanding is needed for a full application, they already see how the acquired knowledge enables more thoughtful decisions, even if not analyzed through mathematical modeling. The information gained was rated highest (87 %) by municipal employees, who frequently need to align various societal groups' individual interests with the community or collective interests in their daily work.

One of the activities within the method – the idea session on thematic visual materials highlighting features of systems thinking – received enthusiastic feedback from participants. They expressed interest in using such materials in their workplaces to support their colleagues' awareness and education on making better decisions with regard to sustainable choices and collective interests (see Fig. 2.17).

Fig. 2.17. Example of a poster idea created in the systems thinking workshop.

The method was validated in events organized by the Vidzeme Planning Region, Zemgale Planning Region, Rīga City Municipality, Jūrmala City Municipality, Ventspils City Municipality, Cēsis Municipality, Dobele Municipality, Preiļi Municipality, and Rēzekne Municipality. These events focused on strengthening human resource capacity and promoting sustainable solutions in public governance, community, and business development.

2.7. Evaluation of the Developed Methods

Experts representing partner organizations, who work closely with various target groups daily, evaluated five different methods using seven key criteria essential for decision-making regarding the implementation of activities. These criteria included information dissemination and education, individual attitude and intention demonstration, stimulating environment creation, adaptability to different target groups, duration of the methods, partner organization involvement, and audience reach (see Table 2.4). Both the criteria and their weights were defined by the experts based on the needs of their organizations and feedback from participants. For methods not previously used in their organizations, experts were provided with detailed information on the purpose, expected outcomes, previous experiences, and participant feedback related to each method.

Figure 2.18 presents the overall evaluation results of the methods developed and validated in this study, as assessed by experts using the TOPSIS approach. The TOPSIS analysis revealed that the Future organization game and sustainability hackathon scored the highest among five experts from partner organizations, with scores of 0.763 and 0.7, respectively, making them the most suitable methods, followed by the digital twin of energy communities (0.425). These results are attributed to the partner organizations' desire to create action-oriented environments that leverage visualization to demonstrate emerging norms.

Table 2.4

Criteria for General Assessment of Methods and Their Weights

#	**Criterion**	**Weight**
C1	Information and education	0.2
C2	A demonstration of an individual's attitude and intent	0.2
C3	Creating a stimulating environment (presence of enablers)	0.2
C4	Adaptable to diverse target groups	0.15
C5	Duration of the event	0.05
C6	The degree of involvement of the partner organization	0.05
C7	Audience coverage	0.15

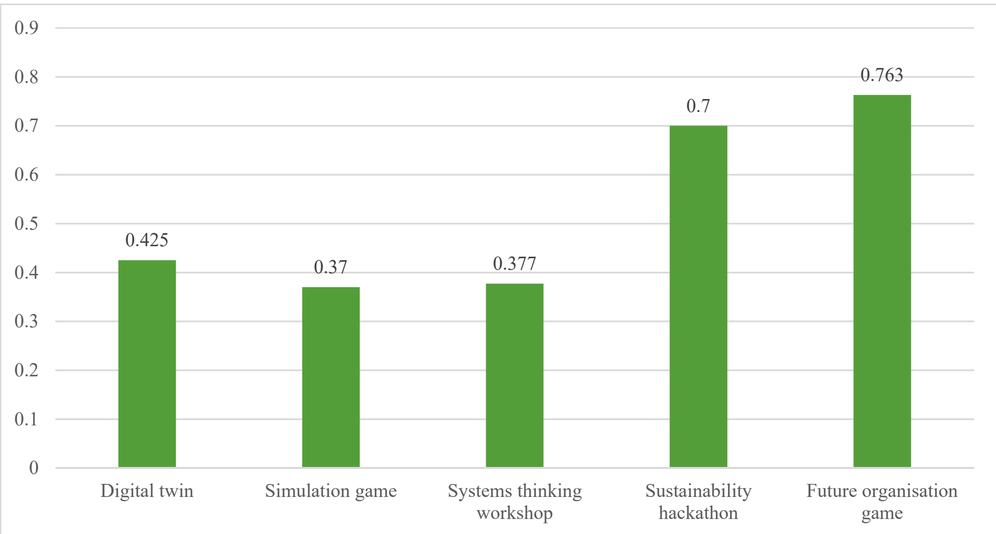

Fig. 2.18. Comparison of evaluations of methods according to general criteria.

Hackathons are traditionally geared toward solving practical problems, often facilitated by intensive collaboration among diverse stakeholders. In contrast, the Future organization game focuses on structuring and aligning internal processes for implementing sustainability strategies. This approach can ensure a higher level of engagement from partner organizations, fostering a microenvironment conducive to active adaptation of participants' mental models. The systems thinking workshop and simulation game received lower evaluations, primarily due to application constraints. For instance, the systems thinking workshop requires careful selection of the target group (e.g., youth might not be the most suitable), while the simulation game imposes some limitations on participants’ creative expressions, as it requires adherence to defined roles with specific attitudes and behavior boundaries.

In addition to the overall evaluation, experts assessed three specific dimensions. The need for audience information and education, along with significant reach, contributed to the high rating of the Future organization game. This method provides participants with practical experience and knowledge that enhance understanding and foster more responsible decision-making. Furthermore, hackathons often attract diverse audiences, which may include a variety of target groups, ensuring wider adaptability and broader impact. The expert assessment process is illustrated in Fig. 2.19.

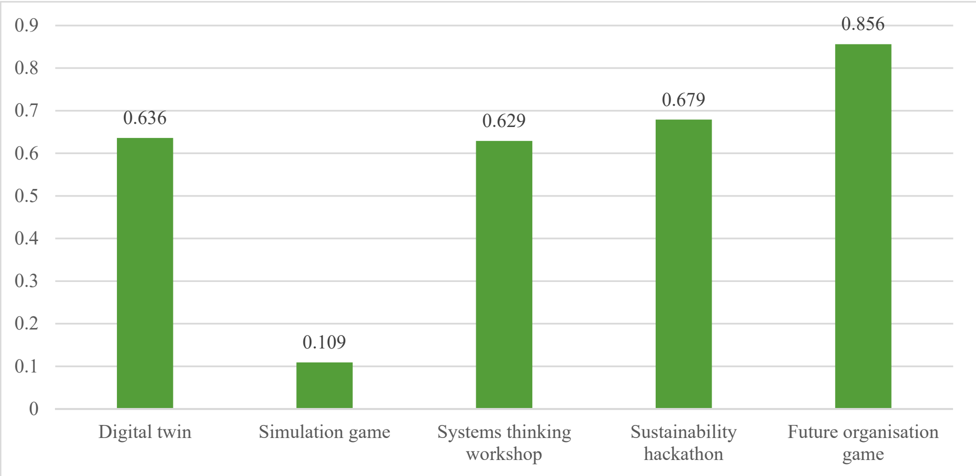

Fig. 2.19. Comparison of method ratings by impact on awareness and education.

When evaluating the remaining two dimensions, experts provided assessments to determine the most suitable methods according to the goals set by partner organizations. The results of these assessments are illustrated in Figs. 2.20 and 2.21. These evaluations reflect the adaptability of each method to meet specific organizational objectives, highlighting the alignment between the intended impact and the strategic direction of the organizations involved.

The application of the TOPSIS method reveals that the content and format of the systems thinking workshop offer the greatest contribution to intention and attitude demonstration in events, as assessed by experts. The second most impactful method is the Future organization game, followed by the energy community digital twin.

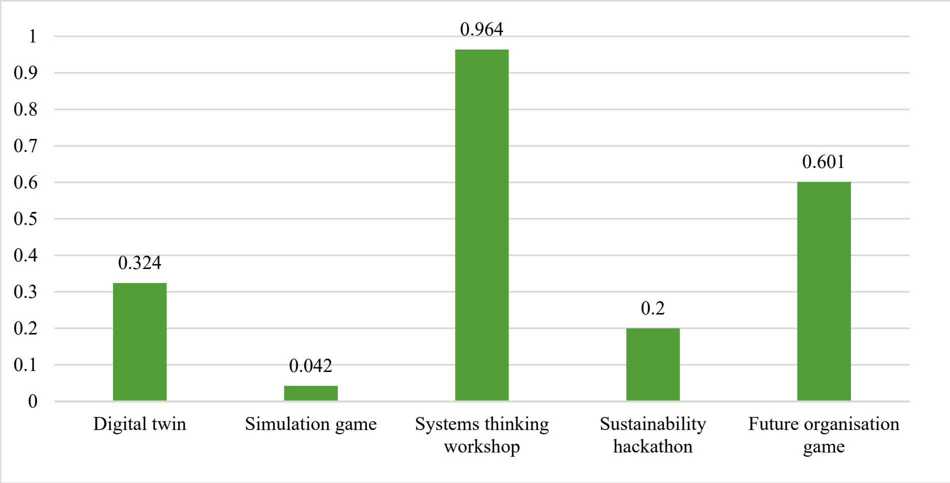

Fig. 2.20. Comparison of method ratings by impact on demonstrating intent and attitude.

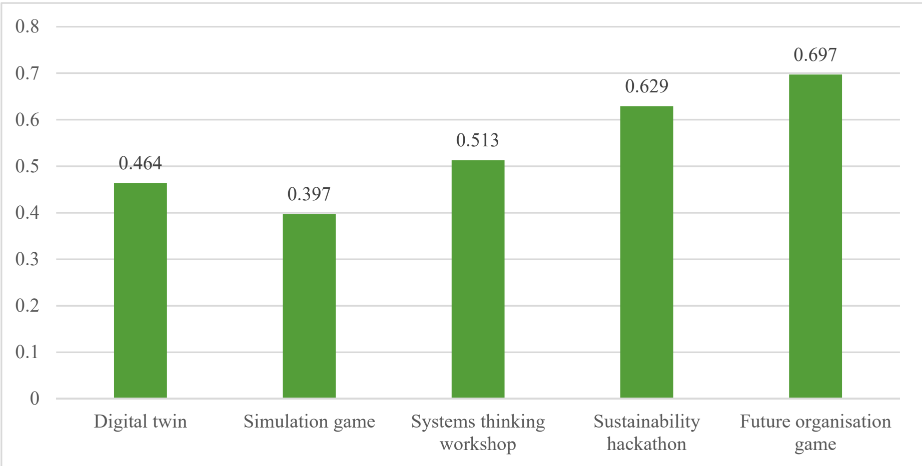

Fig. 2.21. Comparison of evaluations of methods according to the impact on creating an action-stimulating environment.

Considering the specific applications and organizational requirements of each method, 13 commonly encountered parameters characterize the different methods (Table 2.5). These parameters enable partner organizations to evaluate each tool's contribution to their work with selected target groups, providing insight into the effectiveness and adaptability of each method to meet organizational objectives.

Table 2.5

An Overview of the Parameters of the Methods Approved Within the Framework of the Study

Characteristic parameters of the method	The digital twin of energy communities	Simulation game	Systems thinking workshop	Sustainability hackathon	Future organization game
1. Primary objective (TOPSIS results, where 1 is the most relevant):					
1.1. Education and information	3	5	4	2	1
1.2. Demonstration of intent and attitude	3	5	1	4	2
1.3. Action-stimulating environment	4	5	3	2	1
2. Duration of the event, h	2	2	3	8-24	8-16
3. Minimum room size, m^2	50	50	50	100	100
4. Number of participants					
4.1. Minimum number	5	6	12	16	16
4.2. Maximum number	50	30	30	45	45
5. Necessity to pre-selection of participants					x
6. Preliminary preparation, h	2	2	2	8	10
7. Presence of a moderator		x	x	x	x
8. Presence of the organization's management				x	x
9. Engagement of external experts				x	x
10. Technical provision, computer	x			x	x
11. Digitization of results (summary) by activity (to a partner organization for analysis or project reporting purposes)					
11.1. Collection of ideas				x	x
11.2. Feedback	x	x	x	x	x
11.3. Summary of discussion		x	x		x
12. Costs for moderating the event, EUR		300–450	300–450	500–1000	500–1000
13. Provision of catering services					
13.1. Coffee breaks, number	1	1	1	2–4	2–3
13.2. Lunch breaks, number				1–2	1–2

For partner organizations, an essential aspect for more effective planning in implementing methods is conducting sensitivity analysis and employing other multi-criteria decision-making (MCDM) approaches such as AHP, ELECTRE, VIKOR, PROMETHEE, and SWARA, among others. In this study, the primary focus was on the development and validation of methods grounded in scientific approaches, aiming to confirm their substantive applicability. Future research may explore diverse science-based approaches for educating decision-makers, ensuring that these tools align with evolving scientific advancements and practical applications in multi-criteria decision-making.

CONCLUSIONS

1. The study's findings confirm the hypothesis set out in this work: the availability of diverse tools contributes to the development of a climate-responsible society, impacting three critical behavioral aspects – informing and educating, demonstrating attitudes and intentions, and creating an action-stimulating environment. This is supported by the positive evaluations of both participants and representatives from organizations involved in method development and assessment.

2. The aggregated results indicate that the fture organization game received the highest evaluation among field experts, proving most suitable for fostering a climate-responsible future society. Resources required for practical implementation align with the organizational capacity of local governments, and the method's validation demonstrates significant social influence in public education and shifts in mental models.

3. The systems thinking workshop, a scientifically grounded approach in system dynamics, stands out as a unique method for addressing complex social systems. It notably contributes to potential changes in attitude and intent toward environmental issues, especially where diverse opinions and marginal views prevail. Participant and expert feedback, along with workshop outputs (such as visualizations that creatively communicate complex issues), highlight this method's potential to initiate new norms through social influence rather than traditional reward and punishment mechanisms.

4. Results from this study reflect an emerging trend wherein socially and environmentally engineered approaches represent a new and relatively unexamined format, capturing the interest of the public sector as it seeks contemporary tools to engage target groups that are typically challenging to influence.

5. Data analysis indicates that the multi-criteria decision-making method, TOPSIS, can become a transformative and highly valued tool among partner organizations. This approach supports not only thoughtful, sustainable decision-making but also serves as a reliable, democratic digital guideline for the broader public, balancing individual and community interests on environmental and other social issues.

6. The study's engagement with experts and municipalities – validated by United Nations data on realistic scenarios for SDG implementation – positions municipalities as the most suitable and responsive partners in developing a climate-responsible society. This strengthens the practical applicability and future development potential of the research.

7. These findings broaden opportunities for researchers ready to propose "radical innovations" in modern climate-neutral governance. This approach leverages interdisciplinarity at the intersection of social and environmental engineering, offering transformative pathways for sustainable community engagement.

RECOMMENDATIONS

The Doctoral Thesis offers specific recommendations for policymakers, planning region administrators, municipalities, the commercial sector, service providers, the academic sector, and general education institutions, all aimed at fostering a climate-responsible society.

1. For planning regions and municipalities: The author encourages broader adoption of the multi-criteria decision-making TOPSIS approach to reduce public resistance when there are many diverse opinions. By reaching a shared understanding through agreed-upon criteria and weights, TOPSIS provides a transparent and objective decision-making process, thereby increasing community trust in local authorities. Additionally, training employees on systemic thinking archetypes could, over the medium to long term, improve engagement with community members who are currently resistant to compromise.
2. For the commercial sector as clients: The Future organization game is recommended as a practical design-thinking tool to integrate into sustainability strategy development and implementation. This tool allows for comprehensive staff involvement, fostering a culture of shared values and enhancing cooperation across various organizational levels. It could become a strategic part of organizational culture on the path to climate neutrality by actively engaging staff in identifying and implementing sustainable growth opportunities.
3. For service providers: The author suggests creating a list of service-defining parameters and using a multi-criteria decision-making approach to assist clients in selecting the most suitable options for their needs. This approach not only saves time but also minimizes the risk of misinterpretation during planning and implementation.
4. For the academic sector: The author advocates for continued exploration of synergies between social sciences and engineering to combine the strengths of both disciplines. Such collaboration could foster scientific innovation and address gaps in understanding complex social systems, as highlighted in the literature. This study's results demonstrate the potential for practical applications that benefit partner organizations focused on guiding society towards climate neutrality.
5. For general education institutions: Schools are encouraged to adopt any of the methods discussed in the study to enhance student engagement in achieving the UN Sustainable Development Goals (SDGs). Integrating these methods into educational processes would provide a format that aligns with modern educational needs, enabling knowledge acquisition, skill development, personal growth, and community influence.

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