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Analyzing Iranian Public Sector Big Data System Requirements Based on System Design Thinking

Soheil Paydar Fard[a]*, Ali Rajabzadeh Ghatari[a], Mahmoud Dehghan Nayeri[a]

[a] *Department of Industrial Management, Faculty of Management and Economics, Tarbiat Modares University, Tehran, Iran.*

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ABSTRACT

The contemporary world is marked by generation and consumption of vast volume, high velocity, and considerable diverse data, leading us to the concept of big data. In this study, a system design thinking approach was employed to identify the requirements of Iran's public sector big data system. National big data systems would help governments to support their decisions by data and answer to national problems faster. Given the complexity and time-intensive nature of traditional system requirement analysis methods, their practical application in the industry has been declined. Therefore, in this research, system design thinking as an agile alternative for identifying system requirements has been discussed. To accomplish this, the LDA machine learning method has been utilized to analyze approximately 88,000 articles, a thematic analysis on around 600 Instagram and Twitter posts has been conducted, and six experts representing targeted problem persona were interviewed. The objective of this research is to extract insights to serve as a foundation for formulating big data policies in Iran. Findings reveal that Iran big data system requirements can be classified into four categories which indicate on increasing managed access to data while considering security and privacy, encouraging private and public sectors cooperation, transformation to smart governance, and establishing national data organization which would be responsible of data ID documents.

Keywords

Big data, System design thinking, System thinking, Policy, Latent dirichlet allocation (LDA), Topic modelling.

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*Corresponding author
Email: s.paidar@modares.ac.ir

1. Introduction

Our contemporary world can be characterized by the continuous generation and consumption of data. Nowadays, all of us contribute to the production of data, whether through direct content creation or engagement on various platforms. Additionally, development of the Internet of Things (IoT) technology and the increasing usage of smart devices have further amplified the generation of vast amounts of data. The storage, analysis, processing, sharing, transmission, and utilization of this massive amount of data have become a very important concern for governments, organizations, companies, and even individuals in the present era (Fredriksson, et.al., 2017)

In light of the above, a new field of knowledge has emerged that concentrates into applications and concerns related to large-scale, diverse, and high-velocity data. This field of knowledge is big data (Ivanov, et.al, 2013). Governments are among the most significant entities dealing with the creation and utilization of big data. Such data typically holds considerable value and can greatly enhance governance decision-making process (Desouza and Jacob, 2017). However, there are many concerns about the preservation of privacy and security associated with these data (Fredriksson, et.al., 2017).

This study aims to determine requirements of Iran public sector big data system. The lack of this system, caused many problems for Iran governance system including disability to use national data for policy and decision making, data conflicts and cooperation issues between public sector organizations or between them and private sector companies.

In this paper, system design thinking approach has been used to analyse these requirements. In past decades, system thinking approaches and tools have played a crucial role in the development of software systems and system analysis has been a fundamental step in developing a new software system. However, due to the high dynamics and complexity of this field, traditional system approaches and tools are no longer widely applicable, and software industry practitioners generally utilize alternative methods for designing their products (Nerur, et al., 2005; Paetsch, et al., 2003).

In this study, design thinking as a new system approach was used to identify Iran public sector system requirements. To achieve this goal, first an analysis of Iranian opinions on big data on Persian-language social media and news websites was conducted. For this purpose, content from Persian news websites, Telegram channels, Instagram, and Twitter in 2022 were collected, including over 88,000 articles and approximately 3.8 million words.

By applying the Latent Dirichlet Allocation (LDA) method, reserchers were able to extract latent topics from this dataset. LDA is an unsupervised machine learning technique that employs statistical methods to model the thematic structure of a discrete text corpora (Blei, et.al., 2003; Ostrowski, 2015). After that, a thematic analysis on all of the Twitter and Instagram posts was conducted in research dataset.

In continue, researchers examined the results of social media content analysis by interviewing experts. Based on this, a requirement list of Iran public sector big data system was constructed, which can serve as an input for formulating national policies in this field.

2. Literature review

In this section scientific papers and researches about big data and its applications and concerns in the public sector was reviewed. After that, design thinking as a practical research method to answer wicked problems was investigated; Problems like designing a national big data system.

2.1. Big data and its management in the public sector

Currently, the significance of data and the impact of big data on human life are widely discussed. However, it is essential to remember that just two decades ago, the concept of big data was virtually non-existent. Over the past few years, numerous studies have focused on the importance of big data for governments, the public sector, businesses, and citizens (Diebold, 2012).

2.1.1. Definition and background of big data

The term "data" originates from the Greek word "datomai," meaning "things given." In the past, data were primarily non-digital; however, the adoption of information technology by governments led to the generation of vast amounts of digital data. Big data is often defined using the three-Vs model, considering volume, variety, and velocity (Ivanov, et. al, 2012). Some have extended this model to include value, accuracy, and other factors (Chen, et. al., 2014; Wamba, et. al., 2015; White, 2012).

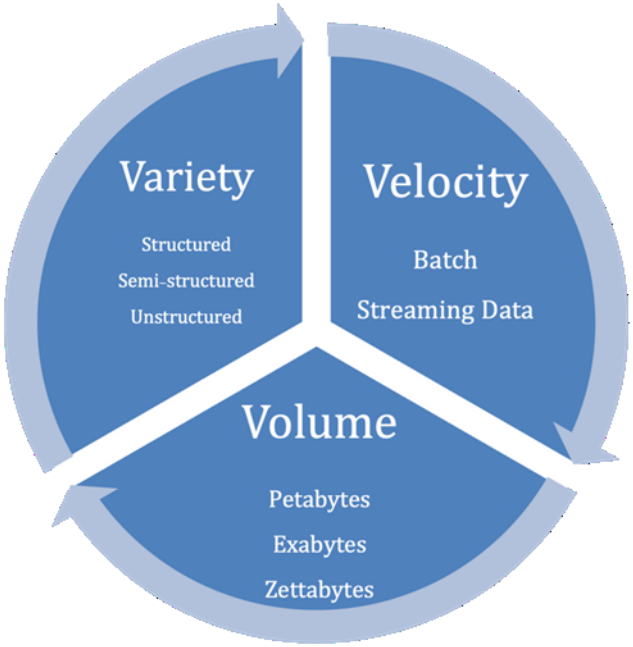

Figure 1. Big data 3Vs (Ivanov, et. al, 2012)

2.1.2. Big data and the public sector

Historically, governments were pioneers in using and storing data. They have dealt with data storage and encoding for various purposes, including administration, law, and governance (Henninger, 2013). The shift to digital technology in the 1990s led to the accumulation of vast amounts of digital data and governments were one of the main owners of large-scale data (Chen, et. al., 2014). So, nowadays big data became particularly relevant for governments and its importance reflected in initiatives such as Barack Obama's executive order to assess big data capabilities for decision-making (Desouza & Jacob, 2017).

Fredriksson, et al (2017), conducted a systematic literature review on scientific papers about big data in the public sector. They reviewed 156 scientific articles in 5 main databases between 2006 and 2015. They have categorized the main challenges of Big Data in the public sector into three areas: data management, ensuring data quality, and ethical and privacy concerns.

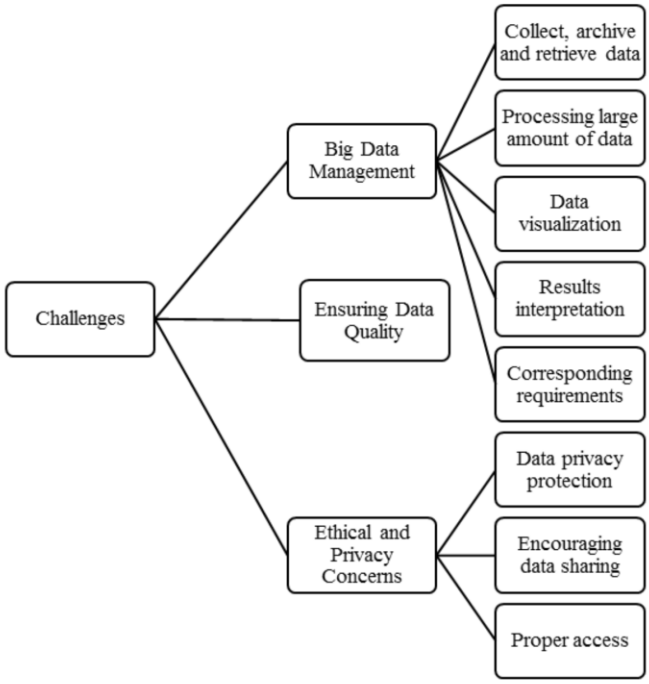

Figure 2- Challenges of big data in the public sector (*Fredriksson, et al, 2017*)

Daniell, et al (2016) focussed on the applications of big data in policy making. Big data can support politicians' decisions and help them to analyse their policies in fields like energy planning, urban transportation planning, medical emergency planning, healthcare, social services, national security, defence, government finance allocation, understanding public opinion, and fire and police services.

Using big data for policy making needs various sources and analyses. These sources and analyses can be categorized into three analyse types: social data analysis, historical data analysis, and predictive data analysis (Rahmanto, et. al., 2021).

Hong, et al (2019) discussed one of the applications of big data in public sector and analyzed role of big data in smart city policies and service design. They analyzed "night owl bus" service in the Seoul, South Korea as a successful public service design and illustrated role of "Big Data-based policymaking" in its success.

In this section the concerns and applications of big data in the public sector were reviewed. Goal of this paper is to find concerns and applications of big data for Iran public sector and identify requirements of a system that address these concerns and applications.

2.2. Design thinking

Tim Brown (2008) defines design thinking as "a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity".

Lockwood (2010) also describes design thinking as “a human-centred innovation process that emphasises observation, collaboration, fast learning, visualisation of ideas, rapid concept prototyping, and concurrent business analysis".

Martin, among other design thinkers, has significantly influenced the field of design thinking with his definition. He characterizes design thinking as the "integration of effective analytical thinking and intuitive thinking" and combining these two distinct models of thinking (Martin & Euchner, 2012).

Micheli, et al. (2019) through a systematic review on all scientific articles published on design thinking found three main conclusions:

1. Design thinking is often used for solving problems, especially wicked problems (Buchanan, 1992).
2. Design thinking is an iterative process with a user-centric focus (Brown, 2008).
3. Some features of design thinking, such as creativity and innovation, are relatively general, while others, like abduction reasoning, are more specific (Micheli, et al., 2019).

Also, they classified conventional tools and methods of design thinking into eight categories:

1. Cognitive methods
2. Personas
3. Customer journey mapping
4. Brainstorming
5. Mind mapping
6. Visualization
7. Prototyping
8. Field experiments

2.2.1. design thinking and its relationship with systems thinking

A concept that has gained attention in various design thinking research studies is systems thinking, which has been referred to by different terms such as system thinking, holistic thinking, and gestalt approach (Micheli et al., 2019).

System thinking methods and tools played a significant role in the software system developments in the past decades, but due to the high dynamism and complexity of this field, traditional system tools are no longer widely applicable (Paetsch et al., 2003; Nerur et al., 2005). Therefore, Investigating the roots of systems thinking and considering innovative system approaches to update these tools becomes essential.

By investigating system methods and approaches observers can find some that aims to solve wicked problems. soft systems methodology, strategic options development and analysis, drama analysis, viable system model, and critical systems heuristics are examples of these aims (Checkland, 2000; Eden and Ackermann, 2001; Bennett and Howard, 1996; Beer, 1984; Ulrich and Reynolds, 2010).

Design thinking is another method that wants to handle wicked problems, so it seems plausible to recognising design thinking as a system approach in system of system methodologies.

3. Materials and methods

To identify the requirements of the Iranian public sector big data system, the following framework was used, based on design thinking approach:

1. Collecting data sets for user's opinions
2. Conducting LDA on data sets
3. Labelling each topic and designing requirements architecture version 1
4. Theme analysis on all collected articles of Twitter and Instagram
5. Analysing problem persona and finding a representative for each persona
6. Interviewing with each expert persona representative
7. Reviewing labels and requirements architecture based on current interview

This model is an iterative model, meaning that researchers repeat last two steps to considering all personas. It is design thinking way to ensure theoretical saturation is achieved.

To better implement the above method, also some design thinking tools were leveraged. Population-based methods such as interviews, and persona analysis and design are tools directly employed in this research. By examining the overall audience of this research, four personas can be identified from a specialized perspective:

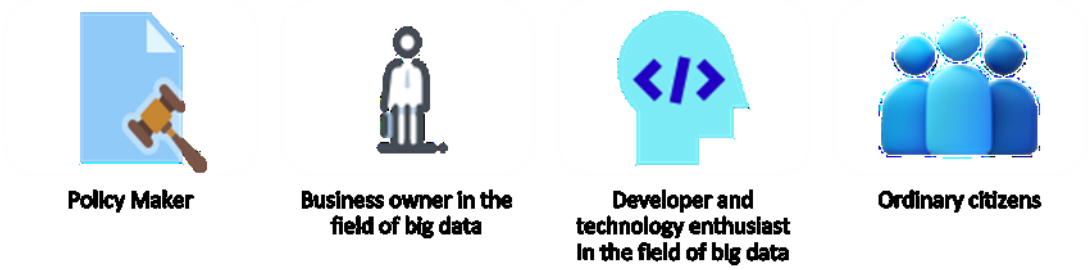

Figure 3- Research persona

In the topic modelling section, the ordinary citizens opinions were investigated. To ensure that experts' opinions were considered and refining topic labels, researchers interviewed with six expert persona representatives. Each of these individuals may adopt either a liberal or conservative approach to the big data field. Therefore, researchers made an effort to consider all persona of this research in interviews, including:

1. Two active policymakers in the Iranian big data field
2. Two business activists in the big data field
3. Two technical figures in the big data field

Each interviewee would be introduced in the next section.

To examine user opinions on big data in the context of social networks, an appropriate search query was designed and conducted searches on three popular social platforms, Twitter, Instagram, and Telegram and Persian news websites, over a one-year period. these media were chosen because of their popularity in Iran.

A search query comprising the term “big data” in Persian Language and in various formats was employed. The search was conducted from December 31, 2021, to December 31, 2022.

The search query was not restricted to obtaining the maximum volume of relevant content. Therefore, during the analysis process, all collected content was thoroughly examined, and those with irrelevant content were removed as noise.

The search resulted 300 tweets and 296 Instagram posts. It is worth noting that owing to the use of the official Twitter programming interface, the retrieved tweets represent all Persian tweets during the specified time period. However, because of various limitations on data collection imposed by Instagram, the search query was applied to users in the Dataak System, encompassing a majority of active Iranian Instagram users.

Table 1- Number of contents by platform

Platform	Number of articles	Number of words
News	85639	3,192,501
Telegram	1692	534,541
Instagram	296	60,504
Twitter	300	13,756

After collecting the content, the text of each article was normalized using the Hazm Persian language normalization algorithm. This normalization enables us to use various quantitative methods to processed text.

In the next stage of this research, researchers focused on topic modelling collected dataset. Topic modelling, one of the most powerful techniques in natural language processing, has gained significant attention in recent years because of its ability to uncover latent thematic structures within large text corpora.

Latent Dirichlet Allocation (LDA) has emerged as a powerful and widely adopted probabilistic model for topic modelling in various domains (Jelodar, et. al, 2019). Introduced by Blei, et al., (2003), LDA provides a generative probabilistic framework for representing documents as mixtures of topics, with each topic being a distribution over words. This influential work by Blei, et al., (2003) laid the foundation for numerous applications in natural language processing, text mining, and information retrieval. Ostrowski (2015) contributed to the literature on LDA by exploring its applications and potential enhancements. Ostrowski's

work likely extended the understanding of LDA in terms of its performance, limitations, and areas for improvement.

To conduct LDA topic modelling on our dataset, after data cleaning, stop-words were identified and a model was trained by extracting five distinct topics from each dataset. In the following table, parameters of our model that used with Gensim (Řehůřek and Sojka, 2010) python library can be reviewed.

Table 2- LDA model parameters

Parameter	Value
Number of topics	5
Number of words per each topic	10
Number of documents in each training chucks	100
Randomness	Used a number as a seed for random function (in this research 42)
Optimizing α	Gensim can use an algorithm to optimize α for best fit the corpora. This algorithm was used with setting the alpha parameter to "auto"

As topic modelling is an unsupervised approach, the discovered topics do not have labels. Subsequently, the identified topics from the media dataset were associated, and labels and descriptions assigned to each topic and after each interview and iteration, all of these were reviewed.

Following this, the theme of all the content collected from Twitter and Instagram were qualitatively analysed. Subsequently, through interviews with six experts representing the three specified expert persona, a deeper analysis was conducted, particularly focusing on the findings from the LDA section. These interviews helped us to gain a better understanding of users, based on the design thinking empathy concept, so in each iteration, the system requirements model was improved and validated.

In conclusion, by summarizing the above points, a comprehensive requirement list of Iran public sector big data system was developed. These requirements, as input in the technical design of Iran's big data architecture, empowers policy makers and engineers to consider various aspects of Iranians' concerns in the design of a new big data architecture.

4. Analysing data

After examining each of the selected platforms using the Latent Dirichlet Allocation (LDA) topic modeling method, five topics in each platform were identified and each topic includes ten keywords. So, the process of labelling each topic started, based on its keywords and researchers knowledge from literature review and some insights from context of our corpora. Also, after each iteration of research, the labels were refined.

The labels assigned to the identified topics on each platform and its keywords can be observed in the following tables.

Table 3- Instagram topics

Topic labels	Topic keywords
Security (At the Macro and international level)	Technology- Artificial Intelligence- Intelligence- International- Big-security- International relations- Peace- Capital- Organization
Business	Business- Company- Big- Technology- Digital- Plan- Presentation- Area-Financial- Development
Future technology	Internet- Intelligence- Artificial- Future- Information- Things- Technology-Smart- Production- Technology
Trending topic	Process- Registration- Period- Revolution- Management- Holding-Industrial- Hour- Big- Conference
The "everybody lies" book and role of big data in social analysis	Book- Lie- Big- #Big_Data- #Artificial_Intelligence- Social- Google- Data-#Technology- #Data_Science

The first topic concentrates on keywords about security. Role of big data in national and international security and concerns like peace, are obvious in this topic. The second and third topics are transparent but the last two ones need more explanation.

The fourth topic is about conferences and events in the field of big data. This topic was labelled as 'trending topic' because it's a sign of attention to big data. The fifth topic is about a book. This book is about big data but its occurrence in our corpora related to a popular TV show and it can be considered as a noise.

Table 4- News websites topics

Topic labels	Topic keywords
Future technology and country development	Intelligence- Artificial- Technology- Area- Development- Country- Iran-Agreement- Year- Social
Legislation	Article- Approved- Technology- National- Country- Subsection-Development- Clause- Production- Ministry
Fifth generation mobile network	Irancell- Digital- Exhibition- Iran- International- 1400- Sentence-Generation- Transformation- Dey
Big data policy-making	Virtual- Space- Commission- Law- Council- Plan- Regulation- Approval-Parliament- Governance
Industrial development	Development- Technology- Information- Mobile- Company- Country-Industry- Big- Smart- Organization

Results of news corpora is more relevant to policy making. One of its reasons is that usually formal news media reflect experts and elites' concerns, but these topics usually suffering lack of contents that reflect ordinary people views. The combination of social media and formal news media would help this research to consider all of problem persona point of view.

Table 5- Telegram topics

Topic labels	Topic keywords
Policy-making (Critique of passive, conservative, and directive policies)	Arena- Settlers- Society- Government- Life- Class- Cave-dwellers- Economy- Three- Monthly
Trending topic (Technical education in the field)	Education- Program- Programming- Learn- Intelligence- Artificial- Want to- Computer- 100- Engineering
Social analysis (Analysis of opinions in social media)	Report- Production- Analysis- Transition- Content- Media- Percentage- Opinion- Revolutionary- Weakness
Business development and large companies	Technology- Big- Digital- Area- Company- Information- Irancell- Social- Iran- Development
Media war and virtual space	Virtual- Space- War- Revolution- Enemy- Honor- Plan- Religious- Approval- Governance

Telegram channels are popular in Iran and many of other media owners, experts and organizations publish their thoughts in these channels. Therefore, its results are really relevant to our concerns and its topics are reflecting concerns of experts, elites, researchers and ordinary people.

The first topic is related to the ‘cave metaphor’. The cave metaphor indicates on open policy making versus passive, conservative, and directive policies. In addition, one of interesting points of Telegram topics are uniqueness of third and fourth topics. It shows higher level of contents of this media in comparison with other sources and it can be rooted on its variety and popularity in Iran.

Table 6- Twitter topics

Topic labels	Topic keywords
Security	Big (Persian Version)- Data- Big- Intelligence- Security- Artificial Intelligence- Free- Network- Virtual- Instagram
Artificial intelligence	Big- Data- Big (Persian version)- Intelligence- Artificial- Area- Analysis- Hand- Year- Account
Social control (China model)	Data- Big- Big (Persian version)- Project- Iran- China- Analysis- Information- Work- Government
Social media big data analysis	Data- Big- Big (Persian version)- Social- Network- Analysis- Government- Engineering- Can't- Publish
Machine learning	Data- Big- Book- Learning- Big (Persian version)- Intelligence- Work- Artificial- Machine- Analysis

Twitter is the last media that its topic was labelled. Political nature of this platform is reflected on its topics. Twitter usually shows thoughts of political citizens and their concerns about social control, like China programs, and ordinary people security and privacy issues can be seen in the table above.

All the topics of each media were presented in the following table:

Table 7- Labels assigned to the identified topics on each platform

Platform	Assigned label
Instagram	Security (at the Macro and International Level) Business Future technology Trending topic The “everybody lies” book and role of big data in social analysis
News websites	Future technology and country development Legislation Fifth generation mobile phones Big data policy-making Industrial development
Telegram	Policy-making (Critique of passive, Conservative, and Directive policies) Trending topic (Technical education in the field) Social analysis (Analysis of opinions in social media) Business development and large companies Media war and virtual space
Twitter	Security (User) Artificial intelligence Social control (China model) Social media big data analysis Machine Learning

Following the above examination, all Twitter and Instagram posts were red, and theme analysis was performed on them. In result, themes of all posts were identified and categorized into five concepts. The table below displays the results of this thematic analysis.

Table 3. Themes and concepts of Instagram and Twitter thematic analysis

Concepts	Themes
Ethics and privacy	Privacy and technology ethics Industrial security National security Social control Social consequences
Creating value from big data	Development of industries and businesses using big data Revenue generation through big data
Applications	Social analysis Prediction Decision-Making Policy making and strategy development Optimization Recommendation Fair allocation in society Identification and alerting of deviation (Error and fraud) Increasing responsiveness to change
Science and technology	Economic transformation with technological revolution and integration with other technologies Application in research across various branches of sciences
Policy and management	Policy-making for big data development Data governance and the open data approach Education, advocacy, and promotion Human resource development and migration of skilled human resources

After theme analysis, the process of interviewing six experts based on three expert persona and two approaches (liberal and conservative) identified in the previous section, was started. In the next table these persona were introduced:

Table 8- Interviewees

Expert code	Biography
Expert 1	Ph.D. in political science and bachelor of computer engendering. Expert of e-governance. Former manager of IT department in Iran free zones organization. Participant in many national IT projects. Worked with reformist and liberal politicians.
Expert 2	Participant in national big data projects. Expert in the field of social analysis based on big data. Partner and consultant of conservative intuitions.
Expert 3	Founder of pioneer big data company in Iran. Worked with many public and private organizations (Liberal point of view).
Expert 4	Founder of one of the well-known social listening and big data based think-tanks. Researcher of the big data field (Conservative point of view).
Expert 5	Chief technology officer of one of the main Iranian big data companies which designed and implemented remarkable big data systems in Iran (Liberal point of view).
Expert 6	Main developer of one of the most important national data platforms of Iran (Conservative point of view).

As expected, liberal interviewees concentrated on applications and benefits of big data and conservative interviewees concentrated on issues like national security; But besides these, some similarities are obvious between them. Interviewees opinion can be summarized as following:

- Lack of a working framework for contribution and cooperation of public and private sector players

When someone speak about public sector big data, he/ she is speaking about data that create and store by many public and private sector players. We have no working framework that these players can share their data together by considering security and privacy issues. This issue prevents forming a working big data system in many cases.

- Service oriented view against security oriented one

Security without service is meaningless. We can store all of our data in a closed system and prevent other players to use it, but there is no difference between this situation and the situation that we have no data. Our experts think that in many cases security concerns are just an excuse to not working.

When we prioritize service versus security, security concerns would be answered by the requirements of each service. For example, a standard access control systems can handle many of security concerns in this field. In addition, many of public sector data sets are open in democratic countries and transparency regulations force the government to publish them.

- Data ID document

One of the main problems of Iran data ecosystem is lack of data ID. Data ID is a standard document that indicates standard model of data presentation, access of these data, privacy statement and procedures to validate the data. Data Id would be a core document in each big data systems and prevent many further problems.

- Standardizing access controls

Designing a coherence access control system is the other main concern of our experts. In the absence of this crucial system. Everything is arbitrary and every organization and data owner would play a random game based on his/her aims and believes. For example, in current satiation, chief data officer of an organization can gives a full access to a data source or completely block any access to his organization data by his aims.

- High level reports and dashboards

Governments use big data to support their decisions and designing better services for their citizens. They cannot achieve these goals without using proper reports and dashboards that represents insights of their society big data.

- Data integration

Data conflicts are one of the main issues of the public sector big data systems. There are many cases that a data has multiple data sources and these sources doesn't represent similar result. This can be caused by data gathering errors, different criteria or deliberated manipulation of data. A working big data system will identify these conflicts and offer procedures for data integrity.

- Preventing corruption and data manipulation

Corruption is one of the most important issues of Iran governance system. National big data systems can play a crucial role to identifying and preventing corruption. Saving summery of each organization data in third party or decentralized databases can help us to identify and eliminate many types of data manipulation events.

By summarizing and discussing all of the above concerns, it illustrates the crucial role of national data organization. This organization can facilitate data standardization in the form of data ID, ensures that access controls are secure, fair and operational, design national flagship projects like big data framework, national big data dashboards, …, and facilitate cooperation between all national big data players, including private and public sector players.

After identifying experts concerns, all of this research findings can be summarized by combining similar concerns. The following table is the result of this process. Our persona concerns and needs discovered by all the iterations were summarized into four main category which each category has some subcategory requirement. All of this process was audited by experts and these requirements were discussed with them as proposed in test stage of design thinking.

Table 9- Iran big data system requirements

Main requirements	Subcategory requirements
Access and security	Security- Access control- Privacy- Data integration
Public and private sector cooperation	Data sharing- Data commercializing- National flagship data projects
Smart and data-oriented governance	Service-orientation- Prediction and alarms- Data-driven decision making
National data organization and data ID document	Legitimation and policy making- Data standardization

5. Conclusions

In this study, the goal was determining requirements of Iran public sector big data system and finding them by focusing on stakeholders of this system. Our findings demonstrate any public sector big data system needs two core components: A national data organization and data ID.

National data organization cooperates with other organizations to identify every data type that should be collected and will determine responsible of this data, forms of data representation, the ways other organization can access this data and data validation process. All of these will be stored in the data ID document and will be shared with stakeholders. By publishing data ID, national data organization can audit security and privacy issues.

A determined data Id would help public and private sector players to collaborate. For example, internet taxies have many valid information about traffic that can help municipality for urban planning. By standardizing access to these data, private companies like internet taxies can sell their data to public sector organizations by checking it compliance with security and privacy concerns and vice versa.

By storing and analyzing standardized data, government can transform itself to a smart government that help it to make better decisions, propose customized service to its citizens, predict social crises and conduct programs to solve them, and eliminate many potential opportunities for corruption.

Finally, one of the most issues of this model is governance of this national data organization. This organization should be superior to all of the power branches including executive, legislation and Judiciary branches, military organizations and other branches of power.

Governance of this organization can be discussed in future studies. Also, discussing convergence of big data with other emergent technologies like blockchain and IoT in public sector can be the other future study that researchers propose.

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Sustainable Human Resources Management, a Strategy Toward Sustainable Organizational Development; Emphasizing Social Sustainability with a Fuzzy Dematel Approach

Amir Hossein Adeli Jazeb[a*], Mohammad Mahdi Alishiri[a], Ali Yaghoubali pourkoundelaji[b]

[a] *Department of Organizational Behavior and Human Resource Management, Faculty of Islamic Studies and Management, Imam Sadiq University(AS), Tehran, Iran.*
[b] *Department of Decision Sciences and Complex Systems, Faculty of Islamic Studies and Management, Imam Sadiq University(AS), Tehran, Iran.*

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ABSTRACT

Human assets have become the foremost source of competitive advantage in today's world trade environment. The rise and improvement of the unused concept of maintainable human asset administration is one of the concepts that puts the organization in line with maintainable advancement. For this reason, analysts, senior directors, and administration specialists, by emphasizing and tending to the issue of human resource administration, look to attain the sustainable development of organizations. This research advances the field of Sustainable Human Resource Management (SHRM) by addressing a notable theoretical gap: the integration of social sustainability factors using the Fuzzy DEMATEL approach. Despite the extensive literature on SHRM, there is a scarcity of frameworks that systematically incorporate social sustainability. Our study employs a Systematic Literature Review (SLR) methodology, meticulously outlining inclusion and exclusion criteria for article selection, spanning from 1984 to 2020. We adopted a mixed-method approach combining qualitative assessments with quantitative Fuzzy DEMATEL analysis. Data were gathered through a survey distributed among 17 experts in both corporate and academic settings, ensuring a robust evaluation of social sustainability factors within HRM practices. The research identified critical social sustainability indicators and examined their interrelationships, providing a nuanced understanding of their dynamics within organizations. The findings not only bridge the existing theoretical void but also offer practical frameworks for organizations aiming to enhance their sustainability through HRM. Recommendations for both practice and future research are discussed, emphasizing the need for more empirical studies to validate the proposed framework.

Keywords

Sustainable human resources management, Sustainable organizational development, Social sustainability of human resources, Fuzzy dematel approach.

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*Corresponding author
Email: ah.adeli@isu.ac.ir

1. Introduction

In recent years, the discourse on Sustainable Human Resource Management (SHRM) has expanded, yet the integration of social sustainability remains underexplored (Garza-Reyes et al., 2019; Nadeem et al., 2019). Current literature focuses predominantly on environmental and economic sustainability, with less attention given to the social dimensions that are equally crucial for comprehensive sustainability practices within organizations Ehnert et al. (2013). This study seeks to fill this void by integrating contemporary insights from the latest studies, particularly those published in the last five years, ensuring that the framework developed is reflective of current challenges and practices.

Whereas supportability is frequently related to fabric and generation procedures administration, Human Asset Administration (HRM) plays a pivotal part in its common integration. Supportability diverts consideration to HRM's capacity to maintain the human asset base inside, contributing to organizational practicality. Later, it is considered to demonstrate a developing interest within the crossing point of supportability and HRM. Maintainable Human Asset Administration (SHRM) is conceptualized as a system for the working relationship and a donor to maintainable improvement (Ehnert, 2009a; Gollan, 2000; Zaugg et al., 2001). Ehnert (2009b) emphasized the need for more SHRM practices, considering sustainability as strategically important for HRM.. SHRM is characterized by Ehnert (2009b) as "the design of arranged or rising human asset arrangements and exercises planning to empower a adjust of organizational objective accomplishment and generation of the human asset base over a long-lasting calendar time and to control for negative affect on the human asset base."

It considers upgrading the existing SHRM writing by conducting a precise audit and proposing a conceptual system for the selection of supportability through SHRM. This paper methodically surveys the concept of SHRM and distinguishes markers of SHRM appropriation, giving important bits of knowledge to specialists, scholastics, and analysts. The consequent areas of the paper are organized as follows:

Segment 2 presents the efficient writing survey; Area 3 dives into the concept, models, and Markers of SHRM, incorporating Natural, social, and financial, whereas Segment 4 examines approximately fluffy Dematel Strategy at that point clarifies In connection to the effect and adequacy of social components of maintainable human asset administration on each other through the conveyance of surveys among 17 human asset administration pros. Finally, Segment 5 presents the created conceptual system and offers proposals with respect to the realization of feasible human asset administration through the investigation of inquiries about

discoveries. At that point, it bargains with the restrictions of the inquiry and makes recommendations for future investigations.

2. Systematic literature review approach

This review critically examines recent contributions to SHRM, particularly those that have emerged in the last five years. These contemporary studies show SHRM's evolving nature and its increasing emphasis on social sustainability factors, which previous studies have not thoroughly addressed. By integrating these up-to-date insights, this research not only aligns with the latest academic discourse but also enhances the theoretical framework by highlighting the importance of social factors in SHRM.

2.1. Statement of the problem

While SHRM is well-documented in terms of environmental and economic aspects, there is a distinct lack of comprehensive models that incorporate social sustainability. This research addresses this gap by proposing a model that integrates social sustainability into SHRM, focusing on factors such as social justice, workforce diversity, and employee well-being. The added value of this study lies in its systematic approach to embedding these social factors into the operational strategies of HRM, thereby providing a balanced perspective on sustainability that supports organizational goals while promoting social equity and employee satisfaction. Table 1 traces the five stages that the SLR experienced.

Table 10. Systematic literature review phases

No	SLR Phase	Objective and methods used
1.	Scope formulation	Defining the scope of research to be in the bounds of Sustainable human resource management
2.	Locating studies	To locate studies, the following criteria were defined:
		□ Duration: 1984-2020
		□ Electronic databases such as Elsevier, Science Direct, Sage, JSTOR, Emerald, Taylor and Francis, Inderscience, IGI, EBSCO, John Willey, and Springer were explored
		□ Keywords: sustainable human resource management, Human Resources and Sustainability, Green Human resource management, and environmental Human resource management
3.	Study selection	Published research papers with sustainability aspect (environmental, social and economic) and its implementation in HRM, were selected
4.	Analysis & synthesis	Identifying the indicators, drivers, barriers, and benefits of SHRM adoption to benefit practitioners, academics, and researchers
5.	Drawing the conceptual framework	Developing a conceptual framework for sustainability adoption through SHRM.

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The SLR enveloped peer-reviewed diary papers traversing the period from 1984 to 2020. 1984 was set up as the base year due to the nonappearance of noteworthy considerations on SHRM sometime recently. The audit considered nearly all inquiries about papers relating to SHRM, green HRM, triple-bottom-line, Vital HRM, and HR and supportability. Different databases, including Elsevier, Science Coordinate, Sage, JSTOR, Emerald, Taylor and Francis, Inderscience, IGI, EBSCO, John Wiley, and Springer, were utilized for writing the investigation. The papers chosen centered particularly on the supportability perspectives (natural, social, and financial) and their integration into HRM.

The introductory look utilized watchwords such as maintainable human asset administration, Human Assets and Maintainability, Green Human asset administration, and natural Human asset administration, utilizing distinctive combinations related to maintainability and HRM. This introductory look yielded 1,105 papers, which were at that point refined by expelling duplications, coming about in 586 papers. A cautious survey of abstracts advance diminished the number by 320 papers. In this way, 266 papers experienced exhaustive evaluation to guarantee arrangement with the inquiry center, and eventually, 163 papers were chosen for consideration within the precise writing audit.

3. Sustainable human resource management

Feasible Human Asset Administration (SHRM) could be a burgeoning field; however, restricted inquiry has been conducted on this subject, fundamentally due to its rising nature (Sosik et al., 2002; Wehling et al., 2009). Agreeing with the definition provided by Jarlstrom et al. (2018), the elemental concept supporting discourses on SHRM is that organizations point to different results to meet the desires of their partners. These results include financial, social, human, and environmental measurements, with organizations frequently seeking after them concurrently, indeed in spite of the fact that one or two may hold more importance for an organization than the others. Numerous organizations readily unveil their financial, social, and biological supportability execution (Schaltegger and Wagner, 2006; Sena and Shani, 2008).

3.1. Models of sustainable human resource management

Economic Human Asset Administration (SHRM) could be a powerfully advancing field, and the writing presents a few profitable models. One scholastically and experimentally approved show, proposed by Zaugg et al. (2001), relates SHRM with workers showing self-responsibility and effectively taking part in organizational decision-making. The victory of SHRM is gaged

from both organizational and representative points of view. Organizational financial value-added, adaptability, and practicality contribute to the organizational see, whereas representative employability, well-being, and self-responsibility contribute to the employee's point of view. Ehnert (2009c) emphasized a maintainable asset administration approach, highlighting organizations' reliance on the survival of their situations. This approach consolidates the partner hypothesis, the resource-based see, and the framework hypothesis. Zaugg's (2001) Swiss demonstration, grounded in observational investigation, gives an orderly conceptualization of SHRM through conceptual and subjective case considers.

Cohen et al. (2012) distinguish three SHRM characteristics: value, well-being, and worker advancement, with five prerequisites, compliance, administration, morals, culture, and administration. De Prins et al. (2014) propose the "Regard, Openness, and Coherence" (ROC) show, centering on regard for inside partners, openness towards natural mindfulness in HR, and coherence in long-term financial and societal maintainability.

Gollan and Xu (2014) pinpoint outside and inner drivers for SHRM, counting advertising, innovation, administrative changes, culture, clients, administration, and administration fashion. Additionally, Kramar (2014) centers on the supportability of human assets, recognizing outside drivers such as advertising elements, innovation, and administrative changes, as well as inside drivers like culture, clients, authority, and administration fashion. Gollan and Xu (2014) unequivocally diagram SHRM results in terms of efficiency, benefit, worker fulfillment, commitment, advancement, value, and well-being. Kramar (2014) classifies results into organizational, social, personal, and environmental measurements, displaying SHRM as an arranged or rising design of HR strategies/practices that accomplish budgetary, social, and biological objectives while supporting the HR base long-term.

In the midst of expanding partner weight, natural concerns are complemented, inciting companies to create arrangements and programs for naturally maintainable trade hones and compliance with natural controls (Yadav et al., 2016). Table 2 outlines the measurements of different SHRM models.

Table 11. Models of sustainable HRM

Author	Model	Dimensions
(Tabatabaei et al., 2017)	Sustainable HRM Model based on BSC	Sustainable HRM within strategic management, Sustainable HRM strategies
(Kramar, 2014)	Sustainable HRM	Sustainable work systems negative externalities
(De Prins et al., 2014)	Respect,openness, and continuity (ROC) model	Respect for the employees, Environmental awareness in perspective on HRM, Long-term approach (economic and societal sustainability and Individual employability
(Mariappanadar and Kramar, 2014)	Sustainable HRM	"Harm" of efficiency-oriented on stakeholders and externalities
(Ehnert et al., 2013)	Practice-Based Model For the Sustainability-HRM Link	Internal and external drivers, Sustainability objectives at the corporate level, HR-related sustainability objectives and HR-related activities
(Ehnert, 2009)	Paradox framework for SHRM	Human capital, Normative interpretations of sustainability, Efficiency interpretations of sustainability
(Martín-Alcazar et al., 2005)	Integrative model	Social responsibility, Efficiency, And substance-oriented understanding of sustainability. Relationship between HRM strategy and corporate strategy
(Zaugg et al., 2001)	The Three Pillars of SHRM	Work-life balance, Personal autonomy in professional development, Employability of the workers

3.2. Indicators of sustainable human resource management

SHRM, a concept characterized as a long-term approach to socially responsible and economically viable recruitment, selection, development, deployment, and release of employees (Thom and Zaugg, 2004), aligns with the Brundtland Commission's sustainability goals. The Commission declares that sustainability can be achieved at three points, with SHRM playing a significant role in this process:Financial, natural, and social, without gambling common life conditions (Ehnert, 2009b). Various ponders have highlighted that Natural, Social, and Financial Maintainability serve as key pointers and variables impacting human asset supportability. Companies are progressively recognizing the interconnecting between maintainability and its effect on their organizations. Thus, organizations are increasingly looking for ways to move into economic substances by emphatically affecting financial, natural, and social perspectives. These changes are moreover impacting HR maintainability.

3.2.1. Environmental sustainability

Natural supportability points to forming a secure environment and endeavors to play down negative impacts while effectively tending to natural issues. Organizations are progressively embracing green administration hones to upgrade their natural execution (Jabbour et al., 2016;

Udokporo et al., 2020). Various consider centering on green administration and green Human Asset Administration (HRM) hones (Ahmad, 2015; Masri and Jaaron, 2017; Mittal and Sangwan, 2014; Opatha and Anton Arulrajah, 2014; Prasad and Agarwal, 2013; Vij and Mumbai, 2013) have highlighted the relationship between green HR hones, such as green enlistment and choice, green preparing and advancement, green execution administration, green compensate frameworks, green worker relations, and favorable natural execution. Guerci et al. (2016) found that green preparation and association, green execution, and green stipend all contribute to environmental performance. Table 3 outlines the pointers for natural maintainability within the setting of SHRM.

Table 12. Environmental sustainability indicators of SHRM

Indicators	References
Green job design	Revill (2000), Daily and Huang (2001), Govindarajulu and Daily (2004), Jabbour and Santos (2008), Renwick et al. (2013), Opatha and Arulrajah (2014), Arulrajah et al. (2015), Tooranloo et al. (2017)
Green employment	Prasad and Agarwal (2013), Jackson et al. (2014), Ahmad (2015), Arulrajah et al. (2015), Tooranloo et al. (2017)
Green selection	Crosbie and Knight (1995), North (1997), Revill (2000), Jabbour and Santos (2008), Renwick et al. (2013), Chan et al. (2014), Opatha and Arulrajah (2014), Arulrajah et al. (2015), Bangwal and Tiwari (2015), Jepsen and Grob (2015), Tooranloo et al. (2017), Wehrmeyer (2017)
Green performance evaluation	Milliman and Clair, (1996), Prasad and Agarwal (2013), Renwick et al. (2013), Jackson et al. (2014), Opatha and Arulrajah (2014), Ahmad (2015), Arulrajah et al. (2015), Tooranloo et al. (2017), Wehrmeyer (2017)
Green training	Cook and Seith (1992), North (1997), Jabbour (2013), Prasad and Agarwal (2013), Renwick et al. (2013), Chan et al. (2014), Jackson et al. (2014), Opatha and Arulrajah (2014), Arulrajah et al. (2015), Guerci et al. (2016), Tooranloo et al. (2017)
Green reward system management	Bhushan and MacKenzie (1992), Crosbie and Knight (1995), Berry and Rondinelli (1998), Ramus (2001), Daily et al. (2003), Govindarajulu and Daily (2004), Prasad and Agarwal (2013), Renwick et al. (2013), Jackson et al. (2014), Opatha and Arulrajah (2014), Ahmad (2015), Arulrajah et al. (2015), Jabbour et al.(2016), Guerci et al. (2016), Tooranloo et al. (2017)
Green compensation system management	Ramus (2002), Fernández et al. (2003), Phillips (2007), Tooranloo et al. (2017)
Green health and employees' safety management	Ditz et al.(1995), Ahmad (2015), Arulrajah et al. (2015), Tooranloo et al. (2017)
Green management of employee discipline	Wright and McMahan (2011), Renwick et al. (2013), Jackson et al. (2014), Opatha and Arulrajah (2014), Arulrajah et al. (2015), Tooranloo et al. (2017)
Employee green relations	Renwick et al. (2013), Ahmad (2015), Arulrajah et al. (2015), Tooranloo et al. (2017)
Green recruitment	Phillips (2007), Stringer (2010), Jabbour (2013), Renwick et al. (2013), Jackson et al. (2014), Arulrajah et al. (2015), Jepsen and Grob (2015), Oates (2017), Wehrmeyer (2017)
Green induction	Crosbie and Knight (1995), North (1997), Revill (2000), Renwick et al. (2013), Opatha and Arulrajah (2014), Arulrajah et al. (2015), Wehrmeyer (2017)
Green HR planning	Arulrajah et al. (2015), Tooranloo et al. (2017)
Green policy implementation	Ahmad (2015), Arulrajah et al. (2015), Tooranloo et al. (2017)

3.2.2. Social sustainability

Social supportability coordinates consideration towards the well-being of current and future eras, emphasizing the objective of upgrading the quality of life and diminishing social imbalance. Organizations endeavor to realize social maintainability by effectively supporting formal and casual forms, frameworks, structures, and connections that enable show and future eras to construct sound and decent communities. Socially feasible communities are characterized by value, differing qualities, networks, popular government, and a high quality of life. Table 4 diagrams the indicators for social maintainability within the setting of SHRM.

Table 13. Social sustainability indicators of SHRM

Indicators	References
Social infrastructure The availability of career opportunities	Ahmad and Schroeder (2002), Chan and Lee (2008), Tooranloo et al. (2017) Stiglitz (2008)
Accessibility	Smith (2000), Tooranloo et al. (2017), Yeh and Ng (2017)
Ability to fulfil the psychological needs	Ahmad and Schroeder (2002), Turkington and Sangster (2006), Chan and Lee (2008), Mampra (2013), Aragon-Correa et al. (2015), Tooranloo et al. (2017)
Social justice	Dempsey et al. (2011), Tooranloo et al. (2017)
Social sustainability design	Dempsey et al. (2011), Tooranloo et al. (2017)
Corporate social responsibility	Peneda Saraiva and Silva Serrasqueiro (2007), Crane et al. (2008), Teck Hui (2008), Tooranloo et al. (2017)
Social sustainability	Littig and Griessler (2005), Bramley et al. (2009), Dempsey et al. (2011), Tooranloo et al. (2017)

3.2.3. Economic sustainability

Financial maintainability is closely tied to take-toll diminishment, the conservation of profitable assets for future eras, and successful asset administration (Garza-Reyes et al., 2019; Munasinghe, 1993; Nadeem et al., 2019). Within the setting of SHRM, maintainability is seen as a common advantage for all partner bunches and a commitment to long-term financial supportability. As per Nadeem et al. (2018), supportability is the mode of improvement that permits financial and social advancement without draining natural assets while following moral, ethical, and socially and financially sound standards. Table 5 traces the indicators for financial maintainability within the domain of SHRM.

Table 14. Economic sustainability indicators of SHRM

Indicators	References
HR efficiency	Copus and Crabtree (1996), Youndt et al. (1996), Tooranloo et al. (2017)
Re-engineering/ Restructuring	Love and Gunasekaran, (1997), Tooranloo et al. (2017)
Cost reduction strategy	Hanegraaf et al. (1998), Tooranloo et al. (2017)
Senior management commitment	Tisdell (1996), Glaser and Diele (2004), Tooranloo et al. (2017)
Development of facilities	Tisdell (1996), Vincent (1997), Tooranloo et al. (2017)
Macroeconomic policies	Copus and Crabtree (1996), Vincent (1997), Hanegraaf et al. (1998), Epstein et al. (2008), Tooranloo et al. (2017)
Employment guarantee	Glaser and Diele (2004), Basu et al. (2009), Jha et al. (2013)

4. Methodology

4.1. Systematic literature review (SLR) approach

4.1.1. SLR Design and implementation

The Systematic Literature Review (SLR) conducted in this study was designed to ensure a comprehensive and unbiased review of existing literature on Sustainable Human Resource Management (SHRM), focusing specifically on the integration of social sustainability factors. The SLR followed a structured process:

1. Definition of Scope and Objectives: The scope of this SLR was to identify and analyze studies that discuss SHRM practices with an emphasis on social sustainability. The primary objective was to assess the extent of existing research and identify gaps in the literature, particularly in terms of theoretical and practical applications.
2. Database and Search Strategy: The search strategy was meticulously designed, covering a wide range of reputable databases including Elsevier, ScienceDirect, Sage, JSTOR, Emerald, Taylor and Francis, Inderscience, IGI, EBSCO, John Wiley, and Springer. The keywords used in the search were carefully selected to ensure a comprehensive retrieval of relevant literature, including combinations of "Sustainable Human Resource Management," "Social Sustainability," "Human Resources," and "Fuzzy DEMATEL."
3. Inclusion and Exclusion Criteria:

   Inclusion Criteria: Articles were included if they were peer-reviewed journal articles published in English from 2015 onwards, focused on SHRM, and specifically addressed social sustainability within organizational settings.

   Exclusion Criteria: Studies were excluded if they were published before 2015, focused solely on environmental or economic sustainability without incorporating social aspects, were not peer-reviewed (e.g., conference papers, book chapters, editorials), or did not

provide empirical data or theoretical frameworks relevant to SHRM and social sustainability.

4. Selection Process: The selection process was rigorous and systematic. Initially, titles and abstracts were screened based on the inclusion criteria, followed by a full-text review to ensure alignment with the research objectives. This two-step screening process was designed to ensure that only the most relevant and recent studies were included in the review, enhancing the validity of the findings.
5. Data Extraction and Synthesis: The data extraction and synthesis process was conducted with meticulous attention to detail. Key information was extracted from each selected article, including author(s), year of publication, research methods, key findings, and the focus on social sustainability within SHRM. This data was then synthesized to map out the current landscape of research and identify theoretical and empirical gaps, ensuring the accuracy of the findings.
6. Quality Assessment: The quality of each included article was assessed based on a set of criteria developed for this study, including the clarity of research objectives, the robustness of the methodology, the relevance of the findings to the field of SHRM, and the contribution to understanding social sustainability.

4.1.2. Outcome of the SLR

The SLR identified a set of articles that collectively delineate the current understanding and gaps in SHRM practices with a focus on social sustainability. The findings from the SLR informed the development of a conceptual framework for integrating social sustainability in SHRM, highlighting the need for further empirical research to validate the proposed models and practices.

"This research proposes a Fuzzy DEMATEL-based framework that not only identifies but also quantifies the influence of various social sustainability factors on SHRM. Doing so fills the theoretical void by providing empirical evidence and a robust methodological approach to integrate these factors into the core strategic operations of HRM. The framework aims to balance the three pillars of sustainability — environmental, economic, and social — within the HRM strategy, thus offering a comprehensive model that can be empirically tested and applied in diverse organizational contexts."

4.2. Dematel technique: A comprehensive approach for structural modeling

The Dematel technique is outlined as a comprehensive strategy for building and scrutinizing structural models involving intricate cause-and-effect associations among factors (Tseng, 2009). This scientific and highly effective tool visually represents complex causal connections through matrices or diagrams. These matrices and diagrams portray the internal relationships among the elements within a system, illustrating the strength of influence and permeability of each element (Patil, 2013). Consequently, the Dematel method is adept at converting the cause-and-effect relationships of criteria into a sensible structural model. Considering the frequent use of expert opinions in the Dematel method, often articulated in non-transparent linguistic descriptions, it is recommended to translate expert language into fuzzy numbers for coherence and to eliminate ambiguity (Pamucar et al., 2017) .To achieve this, a proposed model utilizes Dematel in fuzzy conditions. The Fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) method integrates fuzzy logic with DEMATEL to analyze cause-effect relationships within a system while accommodating ambiguity in expert judgments (Nasri et al., 2022).

In the Fuzzy DEMATEL analysis, we utilized trapezoidal fuzzy numbers to represent the intensity of influence between elements in the model. This choice is due to their ability to more accurately capture the range and uncertainty of expert judgments compared to triangular fuzzy numbers. Four parameters define each fuzzy number: (l,m,n,o)(l,m,n,o), where:

• ll (lower limit) represents the minimum value that reflects the lowest possible level of influence.

• mm (lower mean) signifies a more conservative estimate of influence, still on the lower side but recognized by experts as plausible.

• nn (upper mean) captures a more commonly agreed upon estimate of influence among the experts.

• oo (upper limit) represents the maximum potential influence as perceived by any expert.

For the purpose of this study, the scale used to define these parameters was structured as follows:

0: No influence
1: Very low influence
2: Low influence
3: Moderate influence
4: High influence
5: Very high influence

Each level of influence was subsequently mapped to a trapezoidal fuzzy number constructed based on expert elicitation. For example, a 'Moderate influence' might be represented as (2,3,3,4)(2,3,3,4), indicating a consensus around moderate influence with potential deviations toward low or high based on different expert opinions.

These fuzzy numbers are essential for the Fuzzy DEMATEL calculation as they allow for a nuanced analysis of the interdependencies and influence levels among factors in sustainable human resource management, capturing the inherent uncertainties in expert assessments.

4.3. Sample community and tools

The current research is applied in terms of purpose and descriptive survey in terms of nature and method. Allan Gibb's model (2020) was used to collect the required information from library studies and to determine the indicators that were examined (Gibb, 2020). In fact, for this research, a fuzzy multi-criteria decision-making model using a fuzzy Dematel-based modeling approach, a Dematel-based weighting system in a fuzzy environment, and examining the leveling of indicators and internal connections between factors affecting the development of sustainable human resources Emphasizing social factors, it has been used to rank the importance of influence and effectiveness of each factor.

4.4. Dematel method steps

Step 1: Formation of fuzzy direct relationship matrix

To discern the pattern of relationships among criteria, an n×n matrix is first established. In this matrix, the influence of each element listed in a row on the elements listed in a column is expressed as a fuzzy number. In cases where multiple expert perspectives are considered, each expert is required to complete the matrix. Afterward, the simple average of the utilized opinions is computed, resulting in the formation of the fuzzy direct relationship matrix denoted as "z."in Equation 1.

$$Z\begin{bmatrix} 0 \dots z_{n\sim 1} \\ z_{1\sim n} \dots 0 \end{bmatrix} \quad (1)$$

Table 6 illustrates the direct relationship matrix, which essentially reflects pairwise comparisons of experts (Patil and Kant, 2014). if multiple experts are involved in the assessment, the matrix represents the arithmetic mean of all experts' contributions.

Table 15. Direct relationship matrix

Factors	Social infrastructure	The availability of career opportunities	Accessibility	Ability to fulfil the psychological needs	Social justice	Social sustainability	Corporate social responsibility	Social sustainability design
Social infrastructure	(0.000,0.000, 0.000)	(0.206,0.397, 0.618)	(0.235,0.426, 0.647)	(0.088,0.265,0.500)	(0.324,0.559,0.794)	(0.176,0.397, 0.647)	(0.015,0.147, 0.353)	(0.176,0.353, 0.588)
The availability of career opportunities	(0.059,0.118, 0.206)	(0.000,0.000, 0.000)	(0.059,0.176, 0.353)	(0.132,0.294,0.515)	(0.162,0.353,0.588)	(0.103,0.309, 0.529)	(0.088,0.176, 0.324)	(0.059,0.206, 0.397)
Accessibility	(0.088,0.176, 0.324)	(0.088,0.235, 0.397)	(0.000,0.000, 0.000)	(0.147,0.294,0.471)	(0.250,0.456,0.706)	(0.132,0.309, 0.544)	(0.118,0.250, 0.412)	(0.088,0.265, 0.500)
Ability to fulfil the psychological needs	(0.044,0.147, 0.309)	(0.147,0.265, 0.397)	(0.074,0.176, 0.309)	(0.000,0.000,0.000)	(0.088,0.206,0.412)	(0.221,0.426, 0.662)	(0.118,0.250, 0.426)	(0.147,0.294, 0.544)
Social justice	(0.353,0.559, 0.779)	(0.250,0.456, 0.676)	(0.353,0.574, 0.809)	(0.191,0.382,0.618)	(0.000,0.000,0.000)	(0.279,0.500, 0.735)	(0.235,0.426, 0.662)	(0.279,0.515, 0.765)
Social sustainability	(0.235,0.456, 0.706)	(0.147,0.324, 0.559)	(0.132,0.324, 0.559)	(0.206,0.412,0.647)	(0.279,0.500,0.735)	(0.000,0.000, 0.000)	(0.176,0.338, 0.588)	(0.338,0.574, 0.824)
Corporate social responsibility	(0.147,0.294, 0.529)	(0.103,0.221, 0.397)	(0.309,0.485, 0.721)	(0.088,0.250,0.456)	(0.206,0.397,0.647)	(0.191,0.426, 0.676)	(0.000,0.000, 0.000)	(0.191,0.426, 0.676)
Social sustainability design	(0.250,0.471, 0.721)	(0.162,0.368, 0.574)	(0.176,0.397, 0.647)	(0.118,0.294,0.529)	(0.309,0.529,0.765)	(0.338,0.588, 0.824)	(0.103,0.309, 0.559)	(0.000,0.000, 0.000)

The following table shows the fuzzy range used in the model:

Table 16. fuzzy range used in the model

Code	Linguistic term	L	M	U
0	No influence	0	0	0/25
1	Very low influence	0	0/25	0/5
2	Low influence	0/25	0/5	0/75
3	High influence	0/5	0/75	1
4	Very high influence	0/75	1	1

Step 2: Normalizing the fuzzy direct relation matrix

The following equation is used to normalize the fuzzy direct relation matrix (Table 8):

Table 17. Fuzzy direct relation matrix

Factors	Social infrastructure	The availability of career opportunities	Accessibility	Ability to fulfil the psychological needs	Social justice	Social sustainability	Corporate social responsibility	Social sustainability design
Social infrastructure	(0.000,0.000,0.000)	(0.041,0.079,0.123)	(0.047,0.084,0.128)	(0.017,0.053,0.099)	(0.064,0.111,0.157)	(0.035,0.079,0.128)	(0.003,0.029,0.070)	(0.035,0.070,0.117)
The availability of career opportunities	(0.012,0.023,0.041)	(0.000,0.000,0.000)	(0.012,0.035,0.070)	(0.026,0.058,0.102)	(0.032,0.070,0.117)	(0.020,0.061,0.105)	(0.017,0.035,0.064)	(0.012,0.041,0.079)
Accessibility	(0.017,0.035,0.064)	(0.017,0.047,0.079)	(0.000,0.000,0.000)	(0.029,0.058,0.093)	(0.050,0.090,0.140)	(0.026,0.061,0.108)	(0.023,0.050,0.082)	(0.017,0.053,0.099)
Ability to fulfil the psychological needs	(0.009,0.029,0.061)	(0.029,0.053,0.079)	(0.015,0.035,0.061)	(0.000,0.000,0.000)	(0.017,0.041,0.082)	(0.044,0.084,0.131)	(0.023,0.050,0.084)	(0.029,0.058,0.108)
Social justice	(0.070,0.111,0.154)	(0.050,0.090,0.134)	(0.070,0.114,0.160)	(0.038,0.076,0.123)	(0.000,0.000,0.000)	(0.055,0.099,0.146)	(0.047,0.084,0.131)	(0.055,0.102,0.152)
Social sustainability	(0.047,0.090,0.140)	(0.029,0.064,0.111)	(0.026,0.064,0.111)	(0.041,0.082,0.128)	(0.055,0.099,0.146)	(0.000,0.000,0.000)	(0.035,0.067,0.117)	(0.067,0.114,0.163)
Corporate social responsibility	(0.029,0.058,0.105)	(0.020,0.044,0.079)	(0.061,0.096,0.143)	(0.017,0.050,0.090)	(0.041,0.079,0.128)	(0.038,0.084,0.134)	(0.000,0.000,0.000)	(0.038,0.084,0.134)
Social sustainability design	(0.050,0.093,0.143)	(0.032,0.073,0.114)	(0.035,0.079,0.128)	(0.023,0.058,0.105)	(0.061,0.105,0.152)	(0.067,0.117,0.163)	(0.020,0.061,0.111)	(0.000,0.000,0.000)

Step 3: Calculating the fuzzy total relation matrix

Step 3 of the Fuzzy DEMATEL method involves calculating the Fuzzy Total Relation Matrix (T) in Equation 2. This matrix represents the direct and indirect effects of the criteria (indicators) on each other.

$$\tilde{T} = \lim_{k \to +\infty} (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \ldots \oplus \tilde{x}^k) \quad (2)$$

If each row of the fuzzy number of the total relations matrix is calculated in Equation 3:

$$\begin{aligned} [l''_{ij}] &= x_l \times (I - x_l)^{-1} \\ [m''_{ij}] &= x_m \times (I - x_m)^{-1} \\ [u''_{ij}] &= x_u \times (I - x_u)^{-1} \end{aligned} \quad (3)$$

In other words, first, the inverse of the normal matrix is calculated. It is subtracted from the I matrix, and finally, the normal matrix is multiplied by the resulting matrix. Table 9 shows the complete fuzzy relation matrix.

Table 18. . Full fuzzy correlation matrix

Factors	Social infrastructure	The availability of career opportunities	Accessibility	Ability to fulfil the psychological needs	Social justice	Social sustainability	Corporate social responsibility	Social sustainability design
Social infrastructure	(0.012,0.063, 0.384)	(0.050,0.136, 0.493)	(0.057,0.147, 0.536)	(0.027,0.110,0.484)	(0.076,0.181,0.613)	(0.047,0.151, 0.587)	(0.012,0.082, 0.423)	(0.045,0.137, 0.551)
The availability of career opportunities	(0.018,0.065, 0.320)	(0.006,0.041, 0.277)	(0.018,0.079, 0.371)	(0.031,0.095,0.378)	(0.038,0.116,0.447)	(0.027,0.109, 0.438)	(0.022,0.069, 0.320)	(0.018,0.087, 0.398)
Accessibility	(0.026,0.084, 0.383)	(0.025,0.094, 0.392)	(0.010,0.055, 0.352)	(0.035,0.103,0.413)	(0.058,0.146,0.519)	(0.035,0.120, 0.492)	(0.029,0.090, 0.374)	(0.027,0.107, 0.463)
Ability to fulfil the psychological needs	(0.016,0.073, 0.354)	(0.035,0.093, 0.365)	(0.022,0.082, 0.381)	(0.006,0.043,0.301)	(0.027,0.096,0.439)	(0.051,0.133, 0.478)	(0.029,0.085, 0.351)	(0.037,0.106, 0.440)
Social justice	(0.083,0.180, 0.588)	(0.063,0.163, 0.571)	(0.085,0.193, 0.639)	(0.050,0.147,0.574)	(0.023,0.105,0.565)	(0.072,0.192, 0.687)	(0.056,0.145, 0.537)	(0.070,0.185, 0.660)
Social sustainability	(0.059,0.155, 0.549)	(0.041,0.132, 0.523)	(0.041,0.140, 0.567)	(0.050,0.144,0.548)	(0.071,0.182,0.654)	(0.017,0.091, 0.524)	(0.043,0.123, 0.499)	(0.078,0.185, 0.636)
Corporate social responsibility	(0.040,0.117, 0.480)	(0.030,0.103, 0.455)	(0.071,0.158, 0.549)	(0.026,0.106,0.476)	(0.054,0.153,0.590)	(0.049,0.156, 0.591)	(0.008,0.053, 0.357)	(0.048,0.149, 0.566)
Social sustainability design	(0.062,0.159, 0.553)	(0.044,0.140, 0.527)	(0.049,0.154, 0.583)	(0.034,0.125,0.531)	(0.076,0.189,0.661)	(0.079,0.196, 0.666)	(0.030,0.119, 0.495)	(0.015,0.084, 0.496)

Step 4: De-fuzzifying the values of the complete correlation matrix

For de-fuzzification, the CFCS epiechoic and bell method has been used. The steps of the de-fuzzification method are in Equation 4:

$$l_{ij}^{n} = \frac{\left(l_{ij}^{t} - \min l_{ij}^{t}\right)}{\Delta_{min}^{max}}$$
$$m_{ij}^{n} = \frac{(m_{ij}^{t} - min\ l_{ij}^{t})}{\Delta_{min}^{max}} \quad (4)$$
$$u_{ij}^{n} = \frac{(u_{ij}^{t} - min\ l_{ij}^{t})}{\Delta_{min}^{max}}$$

So that:

$$\Delta_{min}^{max} = \max u_{ij}^{t} - \min l_{ij}^{t}$$

Calculation of upper and lower limits of normal values witn Equation 5:

$$l_{ij}^{s} = {m_{ij}^{n}}/{(1 + m_{ij}^{n} - l_{ij}^{n})}$$
$$u_{ij}^{s} = {u_{ij}^{n}}/{(1 + u_{ij}^{n} - l_{ij}^{n})} \quad (5)$$

The output of the cfcs algorithm is a matrix with definite values.

Calculation of total normalized definitive values witn Equation 5:

$$x_{ij} = \frac{[l_{ij}^{s}(1 - l_{ij}^{s}) + u_{ij}^{s} \times u_{ij}^{s}]}{[1 - l_{ij}^{s} + u_{ij}^{s}]} \quad (6)$$

Table 10 shows the dephased values of the complete correlation matrix.

Table 19. Complete deterministic correlation matrix

Factors	Social infrastructure	The availability of career opportunities	Accessibility	Ability to fulfil the psychological needs	Social justice	Social sustainability	Corporate social responsibility	Social sustainability design
Social infrastructure	0.118	0.193	0.21	0.171	0.248	0.221	0.14	0.205
The availability of career opportunities	0.108	0.081	0.128	0.143	0.172	0.164	0.112	0.139
Accessibility	0.135	0.144	0.106	0.155	0.207	0.183	0.138	0.167
Ability to fulfil the psychological needs	0.121	0.139	0.133	0.087	0.154	0.191	0.13	0.163
Social justice	0.241	0.223	0.259	0.212	0.182	0.266	0.205	0.256
Social sustainability	0.216	0.193	0.208	0.206	0.254	0.165	0.183	0.254
Corporate social responsibility	0.177	0.162	0.221	0.167	0.223	0.225	0.105	0.216
Social sustainability design	0.219	0.2	0.22	0.189	0.26	0.267	0.178	0.155

Step 5: Threshold calculation

All the determined complete correlation matrix values that are less than the mean of the complete correlation matrix are identified and set to zero using Equation 7; in other words, the causal relationship is not considered.

$$S = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} V_{ij}}{m \times n}$$
$$U_{ij} = \begin{cases} V_{ij} & V_{ij} \geq TS \\ 0 & Others \end{cases} \quad (7)$$

Table 10 shows the full correlation matrix with values below the threshold removed. Based on the table, causal relationships between elements are drawn. The threshold value (TS) in this research is equal to 0.1810.181.

Table 20. Complete deterministic correlation matrix with the removal of lower threshold values

Factors	Social infrastructure	The availability of career opportunities	Accessibility	Ability to fulfil the psychological needs	Social justice	Social sustainability	Corporate social responsibility	Social sustainability design
Social infrastructure	0	0/193	0/21	0	0/248	0/221	0	0/205
The availability of career opportunities	0	0	0	0	0	0	0	0
Accessibility	0	0	0	0	0/207	0/183	0	0
Ability to fulfil the psychological needs	0	0	0	0	0	0/191	0	0
Social justice	0/241	0/223	0/259	0/212	0/182	0/266	0/205	0/256
Social sustainability	0/216	0/193	0/208	0/206	0/254	0	0/183	0/254
Corporate social responsibility	0	0	0/221	0	0/223	0/225	0	0/216
Social sustainability design	0/219	0/2	0/22	0/189	0/26	0/267	0	0

Step 6: Final output and create a causal diagram

The next step is to obtain the sum of the rows and columns of the matrix T. We obtain the sum of rows (D) and columns (R) according to the Equation 8.

$$D = \sum_{j=1}^{n} T_{ij}$$
$$R = \sum_{i=1}^{n} \tilde{T}_{ij} \quad (8)$$

Then, according to D and R, we obtain the values of D+R and D-R, which indicate the degree of interaction and the influence of the factors, respectively.

The final output is shown in Table 12.

Table 21. final output

	R	D	D+R	D-R
Social infrastructure	1/336	1/505	2/842	0/169
The availability of career opportunities	1/335	1/048	2/382	-0/287
Accessibility	1/486	1/236	2/722	-0/25
Ability to fulfil the psychological needs	1/331	1/118	2/449	-0/213
Social justice	1/699	1/844	3/543	0/144
Social sustainability	1/682	1/68	3/361	-0/002
Corporate social responsibility	1/191	1/496	2/687	0/305
Social sustainability design	1/554	1/688	3/242	0/133

Figure 1 also shows the pattern of significant relationships. This pattern is in the form of a chart in which the longitudinal axis is based on D + R values, and the transverse axis is based

on D - R. The position and relationships of each factor are determined by a point with coordinates (D + R, D - R) in the device.

Step 7: Interpret the results

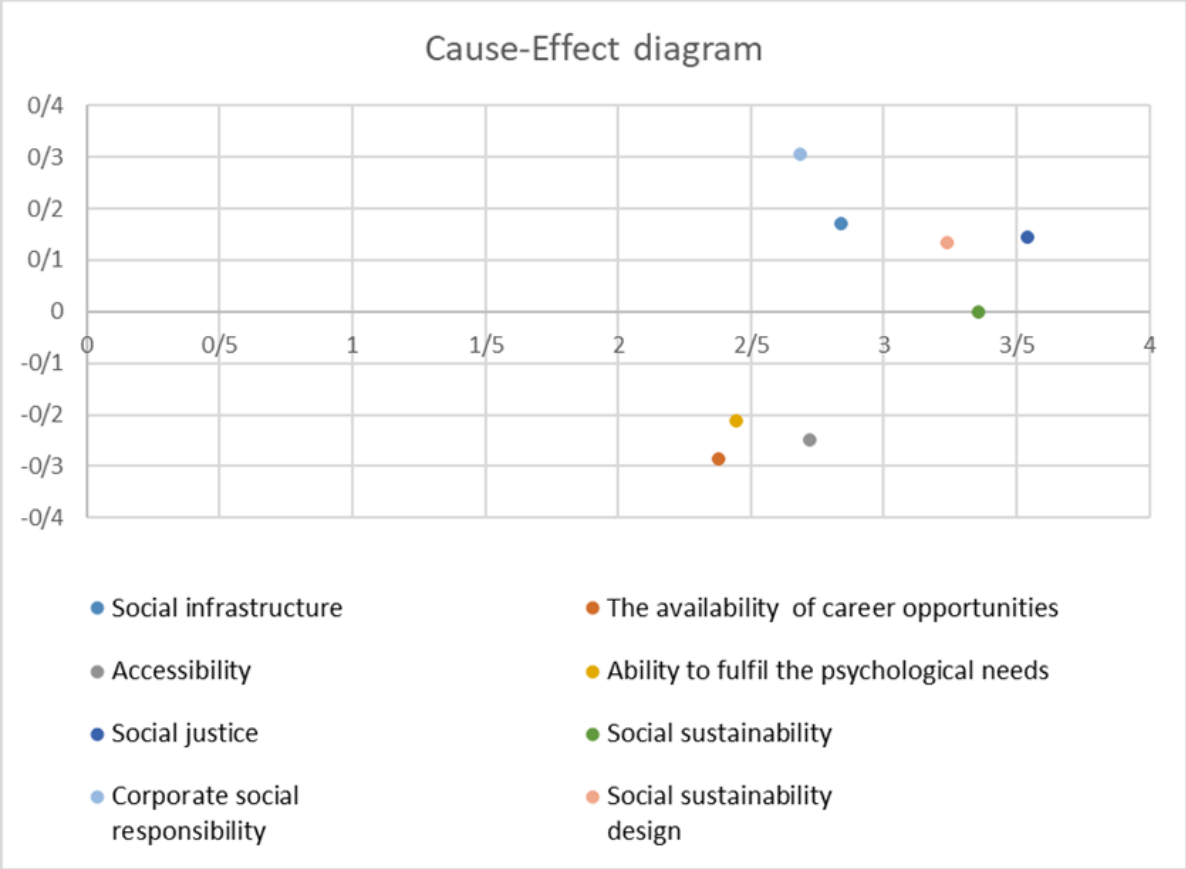

Figure 4. Cause-Effect diagram

According to the above chart and table, each factor is examined from four aspects:

- The degree of influence of variables: the sum of the elements of each row (D) for each factor indicates the degree of influence of that factor on other factors of the system. In this research, social infrastructure has the most influence, and alternative job opportunities, accessibility of disabled employees, ability to satisfy psychological needs, social justice, social sustainability, social responsibility, and social sustainability design are in the following degrees of influence.

- The degree of influence of variables: the sum of the elements of the column (R) for each factor indicates the degree of influence of that factor on other factors of the system. In this research, social justice has the highest effectiveness, and social sustainability, social sustainability design, accessibility of disabled employees, social infrastructure, alternative job opportunities, the ability to satisfy psychological needs, and social responsibility are in the following degrees of effectiveness.

- The horizontal vector (D + R) shows the influence of the desired factor in the system. In other words, the higher the D + R value of an agent, the more interaction that agent has with other system agents. In this research, social justice has the most influence. Social sustainability, social sustainability design, social infrastructure, accessibility of disabled employees, social responsibility, ability to satisfy psychological needs, and alternative job opportunities are in the following degrees of influence.

- The vertical vector (D - R) shows the influence of each factor. To clarify, if D - R is positive, the variable is considered a causal variable, meaning it has a direct impact on other factors. Conversely, if it is negative, it is considered an effect, indicating that other factors influence it.

5. Conclusion

This study investigated the concept of SHRM and its importance in promoting sustainability in an organization. Adopting a systematic literature review approach, it identified indicators, models, and influential factors of SHRM adoption. This research also provides an integrated conceptual framework that can be used to develop a sustainable business adoption through sustainable human resource management (SHRM). The results of the questionnaire distribution among the experts are as follows.

5.1. Key findings

The application of the fuzzy mathematical method revealed significant insights into the interdependencies and influences of social sustainability factors within sustainable human resource management (SHRM). Key findings include:

- Social Justice and Equity: These emerged as the most influential factors, suggesting that fairness in HR practices critically impacts other elements of social sustainability in organizations.
- Employee Well-being and Engagement: These factors are significantly influenced by organizational practices related to social justice, establishing a clear and actionable link between equitable treatment and employee satisfaction and productivity.
- Corporate Social Responsibility (CSR): While CSR was seen as influential, its impact on immediate HR practices was less than that of internal social sustainability factors, suggesting that internal practices may be more critical to sustainable HR outcomes than external CSR activities.

5.2. Analysis of findings

In this research, social infrastructure, social justice, social responsibility, and design of social sustainability are causal and alternative job opportunities, accessibility of disabled employees,

ability to satisfy psychological needs, and social sustainability of the disabled are considered. In this research, social infrastructure has the most influence, and alternative job opportunities, accessibility of disabled employees, ability to satisfy psychological needs, social justice, social sustainability, social responsibility, and social sustainability design are in the following degrees of influence. On the other hand, social justice has the highest effectiveness, and social sustainability, social sustainability design, accessibility of disabled employees, social infrastructure, alternative job opportunities, the ability to satisfy psychological needs, and social responsibility are in the following degrees of effectiveness.

1. Social Infrastructure: Social infrastructure, the backbone of a community's quality of life, including healthcare, education, and housing, is a beacon of hope for employee well-being and enhancing productivity (Shen et al., 2014).

2. The Availability of Career Opportunities: The availability of career opportunities within an organization is a key determinant of employee satisfaction and retention. Providing clear career paths and growth opportunities reassure employees and fosters organizational loyalty (Kong et al., 2012).

3. Accessibility: It's not just a buzzword; it's a commitment. A commitment to ensuring that all our employees, regardless of their abilities, feel valued and included. It's a cornerstone of our inclusive work culture (Hersh, 2015).

4. Ability to Fulfil the Psychological Needs: Fulfilling the psychological needs of employees involves creating a work environment that supports mental health, work-life balance, and a sense of belonging. It is essential for maintaining high levels of employee engagement and productivity (Ryan and Deci, 2000).

5. Social Justice: Social justice in the workplace ensures fair treatment, equality, and respect for all employees, regardless of their background. It encompasses diversity, equity, and inclusion (DEI) practices (George and Jones, 1997).

6. Social Sustainability: Social sustainability involves creating systems and processes that support the long-term well-being of employees and the communities in which organizations operate. It focuses on enhancing quality of life and fostering strong social connections (Colantonio, 2009).

7. Corporate Social Responsibility (CSR): Corporate Social Responsibility (CSR) refers to the ethical responsibility of organizations to contribute positively to society and the environment. It includes philanthropic efforts, ethical business practices, and community involvement (Carroll, 1999).

8. Social Sustainability Design: Social sustainability design focuses on creating work environments and practices that support the long-term social well-being of employees. It involves designing policies and workplaces that promote health, equity, and inclusivity (Dempsey et al., 2011).

9. Implications for Practice: The findings suggest several actionable strategies for HR professionals:

- Integrative HR Policies: Organizations should develop HR policies that integrate social justice and employee well-being into their core operations rather than treating them as separate or secondary concerns.
- Training and Development: Enhance training programs to include modules on equity, inclusion, and diversity to ensure that these values are embedded in all aspects of organizational culture.
- Performance Measurement: Adapt performance measurement systems to include criteria related to social sustainability, such as employee satisfaction and equity, to reinforce these aspects in organizational practices.

5.3. Limitations and suggestions

Like any other research, this has certain limitations. First, it relies entirely on secondary data. Further research can collect preliminary data to simultaneously exploit the concept's value. Second, it provides a conceptual framework that should be examined and validated in survey research.

5.4. Implications for research

These results open several avenues for further research:

- Longitudinal Studies: Future research could undertake longitudinal studies to examine the long-term effects of integrated social sustainability practices on organizational performance.
- Comparative Studies: Studies comparing the impacts of social sustainability in different cultural or industry contexts could provide deeper insights into the adaptability and effectiveness of SHRM practices globally.
- Quantitative Modelling: Further quantitative modeling could refine the understanding of the weight and interaction between different sustainability factors, enhancing the predictive power of SHRM models.
- Research Suggestions
- Empirical Testing: The conceptual framework developed in this study should be empirically tested across various organizational settings to validate its applicability and effectiveness.
- Integration with Other Sustainability Dimensions: Research could explore models that integrate social, environmental, and economic dimensions of sustainability in a unified HR framework.
- Practical Suggestions

- HR Training Programs: Develop and implement training programs focused on social sustainability to enhance awareness and skills among HR professionals.
- Policy Development: Encourage the formulation of policies that explicitly include social sustainability as a core component of corporate strategy.

Research findings highlight several key areas essential for achieving sustainable organizational development:

1. Social Infrastructure: Investing in healthcare, education, and housing enhances employee well-being and productivity. Organizations should invest in social infrastructure by providing employees with access to healthcare services, educational programs, and affordable housing options. Partnerships with local communities and governments can enhance these efforts, ensuring that employees have a stable and supportive environment.
2. The Availability of Career Opportunities: Clear career paths and growth opportunities motivate employees and foster loyalty. Implement a robust career development program that includes regular training, mentorship opportunities, and clear pathways for advancement. Regularly review and update job descriptions and roles to reflect changing market demands and employee aspirations.
3. Accessibility: Ensuring that all employees can access necessary resources and accommodations promotes effectiveness and inclusivity. Ensure workplace accessibility by adhering to universal design principles, providing necessary accommodations, and utilizing technology to facilitate remote work options. Regular audits and feedback mechanisms can help identify and address accessibility issues promptly.
4. Ability to Fulfil the Psychological Needs: Creating a supportive work environment that addresses mental health and work-life balance increases employee engagement. Develop and implement wellness programs that include mental health resources, flexible working hours, and opportunities for social interaction. Encourage a culture of openness where employees feel comfortable discussing their mental health needs.
5. Social Justice: Fair treatment and respect for all employees through comprehensive DEI practices are critical for a harmonious workplace. Adopt comprehensive DEI policies, conduct regular bias training, and ensure equitable hiring, promotion, and pay practices. Establishing a diversity committee can help oversee and promote these initiatives within the organization.
6. Social Sustainability: Integrating long-term well-being goals into corporate strategies supports both employees and communities. Integrate social sustainability goals into the corporate strategy by setting measurable targets related to employee welfare, community engagement, and social impact initiatives. Regularly report on progress and adjust strategies based on feedback.
7. Corporate Social Responsibility (CSR): Ethical business practices and community involvement enhance the organization’s positive social impact. Develop a comprehensive CSR strategy that aligns with the company's values and mission. Engage employees in CSR activities, such as volunteer programs and charitable giving, and ensure transparent reporting of CSR efforts and their impacts.
8. Social Sustainability Design: Designing inclusive, healthy, and flexible workspaces fosters a supportive and collaborative environment. Incorporate social sustainability principles into workplace design by creating inclusive, healthy, and flexible workspaces. Use ergonomic furniture, provide access to natural light, and create communal areas that encourage social interaction and collaboration.

These indicators underscore the necessity for organizations to adopt a holistic approach towards SHRM. By integrating social sustainability factors, organizations can not only achieve a competitive advantage but also contribute to the broader goal of sustainable development. The Fuzzy DEMATEL approach proved effective in identifying and analyzing the complex relationships among social sustainability indicators, providing a nuanced understanding of their dynamics.

Practitioners, as the key implementers, should leverage these insights to implement HRM practices that prioritize social sustainability, thereby fostering a positive organizational culture and long-term sustainability. Future research should focus on empirical validation of the proposed framework and explore additional social sustainability factors that may impact SHRM, empowering the audience with a sense of responsibility.

In conclusion, this study bridges a significant theoretical gap in SHRM literature and offers practical frameworks for organizations. By emphasizing the integration of social sustainability, we pave the way for more comprehensive and sustainable HRM practices.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Future-Oriented Policy Making in Oil Exploration and Extraction Using a System Dynamics Approach

Farzad Amiri[a*]

[a] *Department of Industrial Engineering, Faculty of Engineering Management, Kermanshah University of Technology, Kermanshah, Iran.*

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ABSTRACT

Over the years, the process of studying, exploring, and extracting oil has undergone numerous transformations. On the one hand, the limitations arising from the depletion of oil reserves and the increasing global demand for this valuable commodity, and on the other hand, the growing dependence of industries on fossil fuels, lack of integration in optimal consumption patterns, labor strikes in the oil sector, wars, and political unrest, and instability in the oil market have led major oil-producing countries to implement a wide range of policies to achieve optimal conditions for oil exploration, extraction, and consumption. Moreover, global concerns about the depletion of strategic oil reserves and worries about achieving sustainable and lasting security in the supply of this product make it imperative to seriously address policy-making in the field of exploration and supply. This paper attempts to study the past and present trends of oil exploration and extraction, examine the main and root causes influencing this process through a system dynamics model, and conduct a content analysis on the best policy-making approach for oil exploration and extraction. The Vensim PLE 7.3.5 software was used to analyze the model components.

Keywords

System dynamics, Non-renewable resource management, Oil exploration and extraction, Future-oriented policy making, Causal loop diagram.

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*Corresponding author
Email: f.amiri@kut.ac.ir

1. Introduction

Oil was first discovered in August 1859 in Pennsylvania, United States. Within less than a decade, its production skyrocketed from 500,000 barrels per year to 5 million barrels per year. By 1890, this figure had reached 50 million barrels per year, and in 1922, production soared to about 500 million barrels per year. This increase continued until the early 1980s. From the mid-1980s onward, total production gradually decreased (Table 1), following a cyclical pattern due to the depletion of known oil reserves and the need to search for new sources (Hao, 2023).

Table 22. Top oil producers, exporters, consumers and importers in the world in 2023 (Million barrels per day)

Producers	Production volume	Importers	Import volume	Consumers	Consumption volume	Exporters	Export volume
America	12.9	china	10.6	America	19.6	Arabia	7.4
Russia	10.1	America	6.1	China	15.8	Russia	4.8
Arabia	9.7	India	4.7	India	5.3	Iraq	3.7
Canada	4.6	Japan	3.4	Japan	3.7	America	3.6
Iraq	4.3	South Korea	0.3	Russia	3.5	Canada	3.4
China	4.2	Germany	0.2	South Korea	2.8	United Arab Emirates	2.7
Iran	3.6	Netherlands	1.7	Arabia	2.6	Kuwait	1.9
Brazil	3.4	Italy	1.3	Canada	2.5	Norway	1.6
United Arab Emirates	3.4	France	1.2	Brazil	2.4	Nigeria	1.4
Kuwait	2.7	Spain	1.1	Germany	2.3	Kazakhstan	1.3

Therefore, as discovered resources became depleted, it became imperative to explore new sources because existing resources could not meet the growing demand. Moreover, oil imports alone could not satisfy the generated demand for oil in countries such as the United States. Furthermore, countless resources remained undiscovered, potentially containing substantial amounts of oil. However, discovering new resources required substantial expenditure and the utilization of numerous facilities. Since oil is a non-renewable resource, it should be used in high-value-added industries such as petrochemicals and similar applications. Additionally, it became necessary to search for new energy sources other than fossil fuels like oil to make the best use of the available oil reserves.

Based on forecasts made by the International Energy Agency, until 2025, crude oil will continue to play the main role in meeting the world's energy needs. It will supply 39 percent of the world's energy in 2025. Notably, according to forecasts made in different scenarios, the share of the Persian Gulf region from the total world crude oil production in 2045 will reach 55

percent in the maximum crude oil price increase scenario and 75 percent in the minimum crude oil price increase scenario. Therefore, providing effective solutions to ensure the security of crude oil supply and production and reduce its vulnerability to unforeseen factors will be of great importance for the countries of the region, including the Islamic Republic of Iran (Sulaiman et al., 2024).

1.1. Future-oriented policy making

Future-oriented policymaking refers to a process in which decision-makers and policymakers actively and consciously try to formulate plans, strategies, and policies that not only address current needs and challenges but also Prepare for possible future developments and challenges. This type of policy is particularly important for several reasons and includes various principles and methods. Reasons for the importance of Future-Oriented Policy Making:

- Anticipating rapid and complex changes: In today's world, technological, economic, social, and environmental changes are occurring rapidly. Future-Oriented Policy Making helps governments and organizations adapt to these changes and take advantage of new opportunities.
- Risk management and uncertainty: Due to the uncertainties in the future, Future-Oriented Policy Making helps to identify and manage possible risks and challenges.
- Sustainability and long-term development: Future-Oriented Policy Making focuses on sustainable and long-term development in such a way that resources and the environment are preserved for future generations.

1.2. Principles of future-oriented policy making

(1) Foresight: using foresight tools and methods such as scenario planning, trend analysis, and forecasting to identify possible future changes and challenges.

(2) Flexibility: Creating flexible policies and strategies that can quickly adapt to changes and new conditions.

(3) Participation and Collaboration: Encouraging broad participation and cooperation from various stakeholders including the public, private, civil society, and the general public to gather diverse views and information, making everyone feel valued and integral.

(4) Integration: coordination and integration between different policies and programs in order to avoid contradictions and strengthen efficiency and effectiveness.

(5) Sustainability: Focusing on sustainable development and preserving resources for future generations in all policy dimensions.

1.3. Future-oriented policy methods and tools

(6) Scenario Planning: Designing and analyzing different scenarios to better understand possible future paths and prepare for each of them.

(7) Trend Analysis: This method is crucial for identifying and investigating macro trends and their effects on the future. It is a key part of strategic planning that can help businesses adapt to changing market conditions

(8) SWOT Analysis: This evaluation of strengths, weaknesses, opportunities and threats related to policies and strategies is a fundamental part of strategic planning. It's a comprehensive tool that can guide decision-making and strategy development.

(9) Strategic Mapping: drawing strategic maps to identify the paths to achieve long-term goals.

(10) Surveys and Public Consultations: Use surveys and public consultations to gather broad stakeholder information and views.

(11) Policy Making using System Dynamics: System dynamics offers a framework to model and simulate complex systems. It allows us to see the bigger picture and visualize the outcomes of various policy scenarios, taking into account various factors and their interdependencies.

1.4. System dynamics

In recent years, system dynamics has been used as an effective technique in the analysis and development of resources (Lee et al., 2023). This technique was developed by Forrester and is presented as a problem-solving approach for complex issues with an emphasis on structural aspects (Forrester, 1997).

Systems are defined and modeled based on causal relationships. The models include the following variables (Camps-Valls, 2023):

(1) State variable, which shows the state of the system,

(2) Rate variable, which shows the rate of change of state variables at any given time,

(3) Auxiliary variables, which explain the relationships in the model and make it understandable.

System dynamics was initially used as a methodology to study industrial management issues and has since been used to analyze social systems such as population control mechanisms and food supply (Meadows, 2004; Madadyniaa et al., 2024). System dynamics plays an important role in understanding the long-term mutual effects of a system. This approach has been applied to many issues such as financial planning, solid waste management (Rafew and Rafizul, 2023; Ng and Yang, 2023), forecasting the state of greenhouse gases in the world, supply chain

management, transportation management, and technology policy analysis (Camps-Valls, 2023). In the energy sector, this approach was first used in the United States for gas supply. Its research focused on the long-term effects of demand growth, resource depletion, price, and financial and environmental constraints for the development of new resources (Karbasioun et al., 2023). In this paper, an attempt has been made to develop a dynamic model for oil resources to examine various policies in the field of oil exploration and extraction, as well as the depletion of oil resources along with growing demand.

2. Literature review

Several studies have been conducted in the field of oil exploration and extraction using dynamic systems. A system dynamics model was presented by Kiani and Pourfakhraei (2010), which considers the feedback between supply and demand and oil revenue of the existing system in Iran, considering different sectors of the economy. By using a systems approach, Hosseini et al. (2016) developed a conceptual framework to demonstrate various (economic and financial, technological, political, demographic, and industrial) factors that impact the dynamics of the futures and spot prices with their interrelations. Espinoza et al. (2019) developed Hubbert-based models to project future oil extraction in Ecuador. Hendalianpour et al. (2022) designed a system dynamics model to simulate criteria affecting oil and gas development contracts. Raj et al. (2023) investigated a system dynamics approach to evaluate the oil and gas supply chain. The review of the literature shows that hardly any studies have been done in the field of futuristic policy in oil exploration and extraction using the system dynamics approach. As a result, this field will be examined further.

In addition, Jenkins et al. (2011), in their book entitled Cost-Benefit Analysis for Investment Decisions" used the economic evaluation of oil exploration projects according to the approach of cost-benefit ratios. Robinson and Scott (2016) published their research in the field of oil exploration with a strategic planning approach in the book "Strategic Planning for the Oil and Gas Industry" has published. O'Sullivan and O'Sullivan (2016), in the article "Reservoir Modeling and Simulation: A Case Study" examined the modeling and management of oil resources through simulation in a case study reservoir. AL-Mahasneh (2017), in the article "Optimization of drilling operations in oil and gas wells" has optimized oil exploration and extraction operations through numerical modeling. Lisitsa (2019), in her article entitled "Supply-chain Management in the Oil Industry" studied the optimization of oil extraction supply and logistics processes in order to reduce costs and increase efficiency with the approach

of supply chain management. Ponomarenko et al. (2022), in their book entitled "Economic Evaluation of Oil and Gas Projects" analyzed oil projects in the field of oil exploration and extraction through the management of technical, financial, and environmental risks.

Although each of the above researches examined a special aspect of oil exploration and extraction, due to the static nature and structural limitations of the future-oriented policy, most of them are unable to correctly predict the future situation, especially when combining different scenarios. Based on this, current research tries to increase decision-makers predictive power by correctly understanding this issue and using the capacity of dynamic system simulation, especially in the combined use of effective variables in future-oriented policies and paying attention to their dynamics.

This issue is considered an outstanding feature and innovation for managers and decision-makers in the oil industry management and planning field.

3. A system dynamics model

Oil, as a pivotal capital resource, is a cornerstone of the economic development of countries. However, the global limitation of oil resources, combined with escalating production and consumption, is leading to a decline in proven oil reserves. This, in turn, is driving up the cost of this precious material , including production and exploration costs. Therefore, in light of the oil market fluctuations, the changing energy landscape, evolving consumption patterns, and the diminishing proven oil resources, it is crucial for countries to develop targeted policies. These policies should address key factors influencing the industry, such as exploration, extraction, production, consumption, export, import, and the promotion of alternative energies. It is obvious that, due to the dynamic nature of the components and the complexity and diversity of the influencing factors, the dynamic system approach is considered one of the best policy methods in this field.

It should be noted that the adoption of ineffective policies based on trial and error, in addition to imposing a lot of costs on countries, caused a crisis in this industry due to the mismatch of effective components, which has adverse economic and social consequences.

It should be noted that the adoption of ineffective policies based on trial and error, in addition to imposing a lot of costs on countries, has caused a crisis in this industry due to the mismatch of effective components, which has adverse economic and social consequences.

Given the complexity of the behavior of a non-renewable energy resource system, the behavior of the non-renewable energy system is examined under a system dynamics model in

order to investigate the mutual effects of influential factors, such as the volume of existing reserves, exploration costs, total costs, investment in exploration, price demand, usage rate, sales revenue, discovered reserves, and extraction costs (Lerche, 2004). This model analyses the necessary policies to achieve a set of long-term goals for the optimal use of crude oil.

3.1. Model components

Since non-renewable resources such as oil, coal, and natural gas are limited, they require comprehensive planning and precise development. To make more effective use of these resources, it is necessary to consider the long-term results of current efforts. Therefore, decisions must be made based on long-term analyses to ensure that relevant considerations are applied in all aspects. Figure 1 shows the causal loop diagram of the related model.

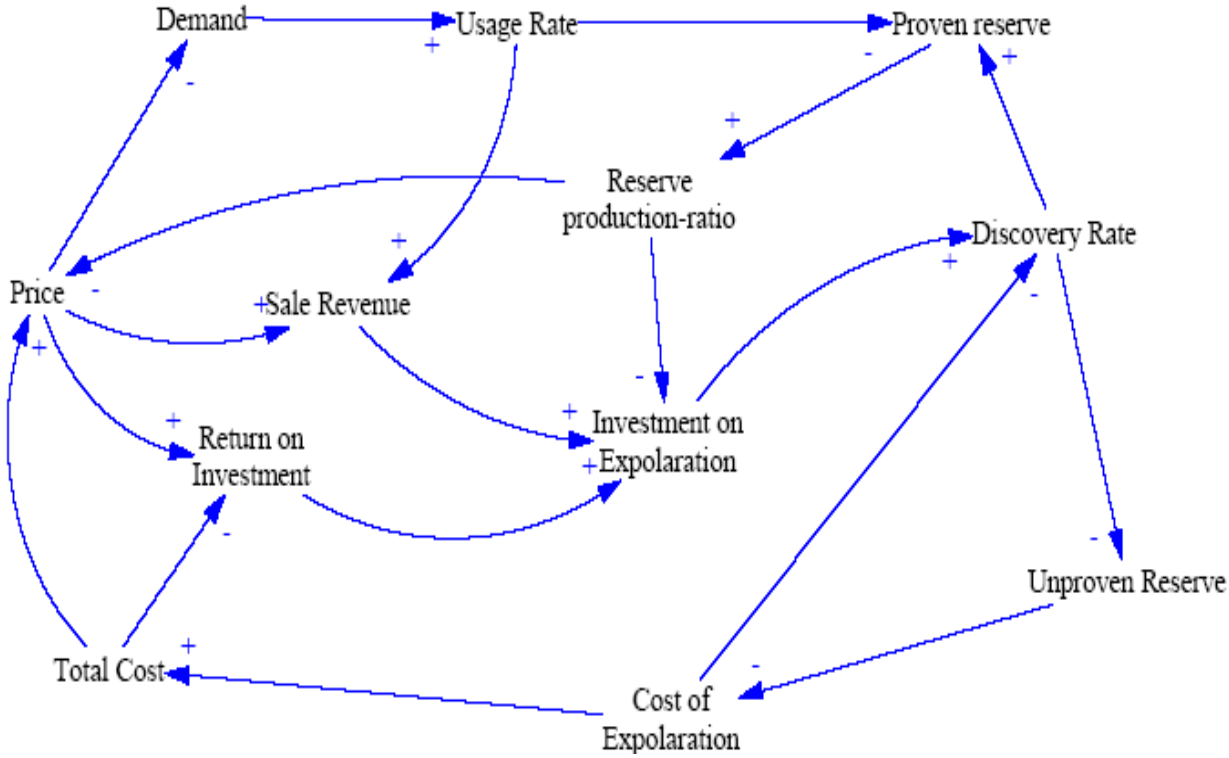

Figure 5. Causal loop diagram of the model

According to the above diagram, two important state variables can be identified: first, the Proven Reserve, and second, the Unproven Reserve. As the amount of undiscovered resources decreases, the exploration cost increases because the search must focus on inaccessible and difficult areas (Adelman, 2002; Sasraku, 2016). On the other hand, fewer resources will be available over time. Therefore, an increase in exploration costs will lead to a decrease in the discovery rate, resulting in a slower decrease in the amount of undiscovered resources.

Additionally, an increase in exploration costs will lead to an increase in total costs, which will consequently result in a decrease in the Return on Investment. An increase in the production rate decreases the Reserve-Production Ratio, and an increase in the Proven Reserve leads to an increase in the Reserve-Production Ratio.

On the other hand, a decrease in price will lead to an increase in demand, which in turn will cause the consumption rate to rise and, consequently, an increase in sales. It will naturally lead to an increase in investment in exploration until the Reserve-Production Ratio reaches the Desired Reserve-Production Ratio (Peng and Luo, 2022). Figure 2 shows the flow diagram of the model on which the simulation will be based.

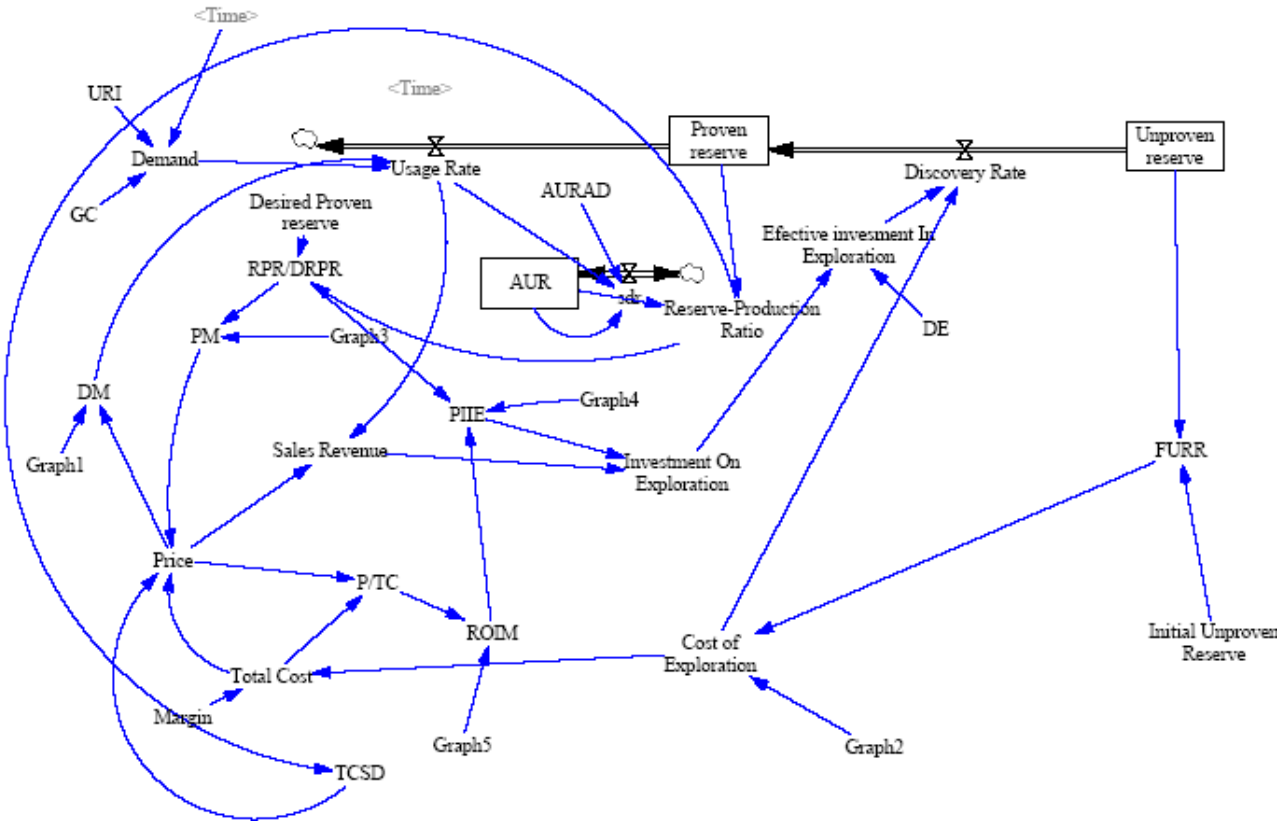

Figure 6. Flow diagram of the model

3.2. Auxiliary variables

The first auxiliary variable used in the model is FURR, which is the ratio of undiscovered reserves to the initial undiscovered reserves at any given time. Figure 3 shows the graph related to the Cost of Exploration as a function of FURR.

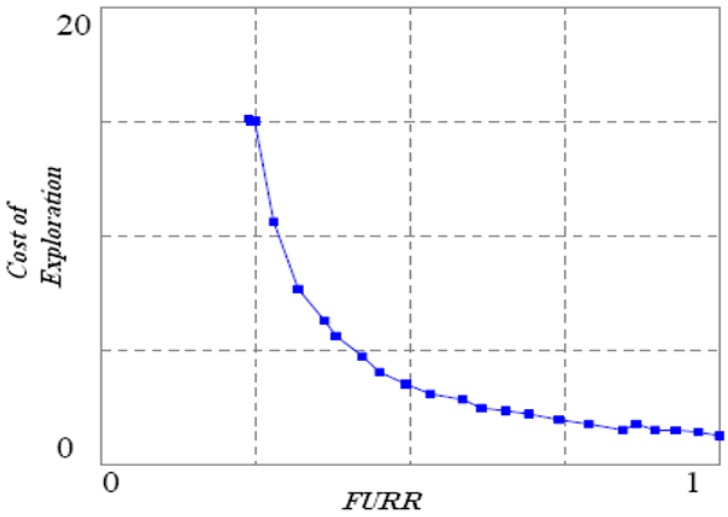

Figure 7. Cost of exploration versus FURR

As evident from the figure, as FURR decreases, the Cost of Exploration increases. The term "Reserve-Production Ratio" represents the ratio of Proven Reserves to the Average Usage Rate (AUR), indicating how long the discovered resources will last at the current consumption rate. Additionally, the Total Cost affects the Price through a third-order delay function (Adelman, 2002). Furthermore, to calculate the Total Cost, the Margin coefficient, which essentially converts the Cost of Exploration into the Total Cost, must be multiplied by the Cost of Exploration. The Price Multiplier (PM) indicates the producer's response to changes in the Reserve-Production Ratio (Figure 4).

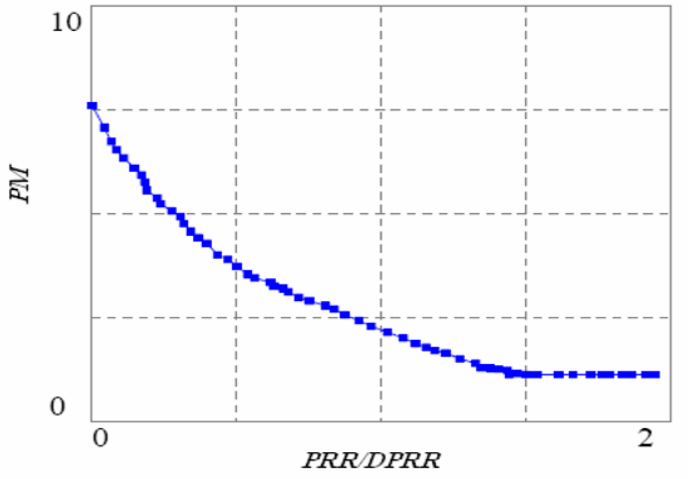

Figure 8. Price multiplier versus PRR/DPRR

From Figure 4, it has been observed that as the Reserve-Production Ratio increases, the Price Multiplier (PM) decreases. This is because the number of years for which the discovered reserves can be used exceeds the expected years of use. Consequently, the price decreases.

Therefore, when the Usage Rate increases, the Reserve-Production Ratio decreases, and the price at which the producer is willing to supply increases. Another logical assumption, derived from statistical analysis of consumption results in developed countries like the United States, shows that the growth in oil demand follows an exponential function with a 7 percent growth (Sasraku, 2016). However, these percentages may be revised in some regions to implement different policies. The Demand Multiplier (DM) represents the consumers' response to price changes. In fact, the consumers' response to price increases is negative (decreasing).

The sales revenue is determined by multiplying the price by the usage rate. Similarly, the Return-On-Investment Multiplier (ROIM) is obtained based on the ratio of Price to Total Cost (P/TC) through the graph given in Figure 5. When the average price is lower than the total cost, the investor decreases their investment, and when the ratio of the average price to the total cost (P/TC) is greater than 1, the producer increases their investment in exploration.

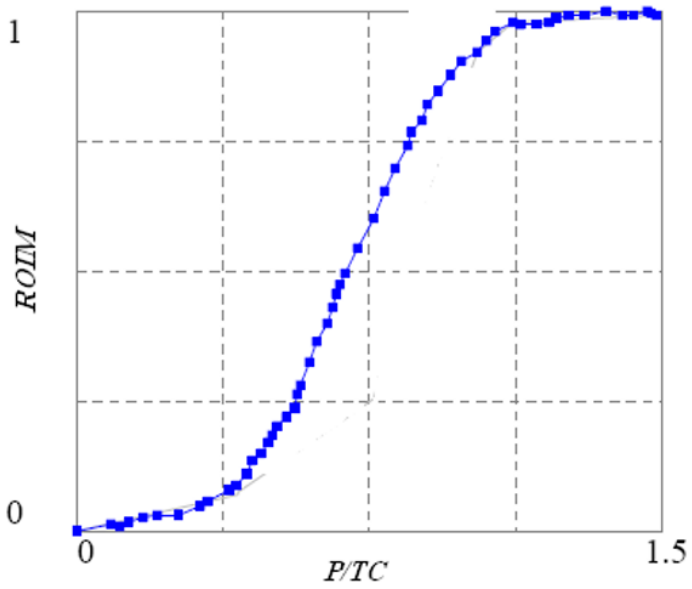

Figure 9. Return on investment multiplier versus P/TC ratio

The percentage of revenue invested is not only a function of ROIM but also a function of PRR/DPRR. When the PRR/DPRR ratio is less than 1, the investor decreases their investment, and when the PRR/DPRR ratio is greater than 1, the investor increases their investment. Figure 6 shows the percentage of revenue invested in exploration as a function of the PRR/DPRR ratio.

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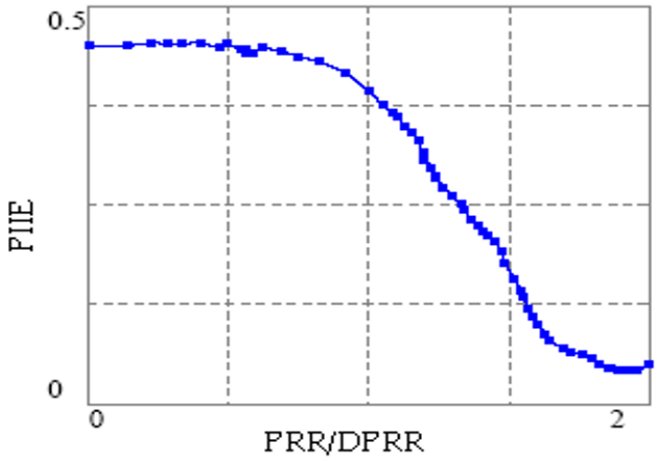

Figure 10. Percentage of investment in exploration versus PRR/DPRR

Investment in exploration is equal to the product of sales revenue and the percentage of revenue invested in exploration (PIIE). Investment in exploration affects the effective investment in exploration based on a third-order delay function. This third-order delay is such that the result of investment in exploration, due to the time delay caused by finding a suitable location for drilling, drilling the well, and accurately estimating the size of the discovery, cannot be accounted for in the first 4 to 5 years.

The percentage of revenue invested in exploration (PIIE) is expressed as a function of PRR/DPRR. As PRR increases, the percentage of investment in exploration decreases, and as PRR decreases, the percentage of investment in exploration increases (Lerche, 2004).

The formulas and types of each variable are mentioned in Table 2. As a result of running the model with the initial values given in Table 2, the following results are obtained.

Table 23. Initial values and model formulation

Variable	Type	Formulation
Unproven reverse	State	"Discovery Rate"
Proven reserve	State	"Discovery Rate-Usage Rate"
FURR	Auxiliaries	"Unproven reverse/Initial Unproven Reserve"
Initial Unproven Reverse	Auxiliaries	4.00E+11
Cost of Exploration	Auxiliaries	Graph2(FURR)
Discovery Rate	Rate	Effective investment In Exploration/Cost of Exploration
Total Cost	Auxiliaries	Cost of Exploration*Margin
Margin	Constant	3.7
ROIM	Auxiliaries	Graph5("P/TC")
P/TC	Auxiliaries	Price/Total Cost
Price	Auxiliaries	PM*SMOOTH(Total Cost, TCSD)

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Variable	Type	Formulation
TCDSD	Auxiliaries	Reserve-Production Ratio
Sales Revenue	Auxiliaries	Price*Usage Rate
Investment on Exploration	Auxiliaries	PIIE*Sales Revenue
Effective investment In Exploration	Auxiliaries	DELAY3(Investment on Exploration, DE)
PIIE	Auxiliaries	Graph4("RPR/DRPR")*ROIM
PM	Auxiliaries	Graph3("RPR/DRPR")
RPR/DRPR	Auxiliaries	Reserve-Production Ratio/Desired Proven reserve
Desired Proven reserve Ratio	Constant	7
Reverse-Production Ratio	Auxiliaries	Proven reserve/AUR
DM	Auxiliaries	Graph1(Price)
Usage Rate	Rate	MIN(Proven reserve , Demand*DM)
AUR	State	Sdr
sdr	Rate	(Usage Rate-AUR)/AURAD
UR1	Constant	5.45E+09
URI	Constant	9.23E+07
UR1	Constant	
GC	Constant	0.07
GC1	Constant	0.07
DE	Constant	4.5
Demand	Auxiliaries	URI*EXP(GC*(Time-1900))
AURAD	Auxiliaries	1
Graph1	Look Up	
Graph2	Look Up	
Graph3	Look Up	
Graph4	Look Up	
Graph5	Look Up	

Figure 7 shows that with the initial values considered for the parameters and state variables, the demand increases by 7% per year, and accordingly, the undiscovered reserves decrease. This decrease was not very noticeable until the year 2000, but after that, it became significant, reaching zero by 2040. Additionally, the discovered reserves increase until they reach their maximum value in 2040 and then decrease until they reach zero. The potential demand growth, as shown in Figure 7, increases exponentially.

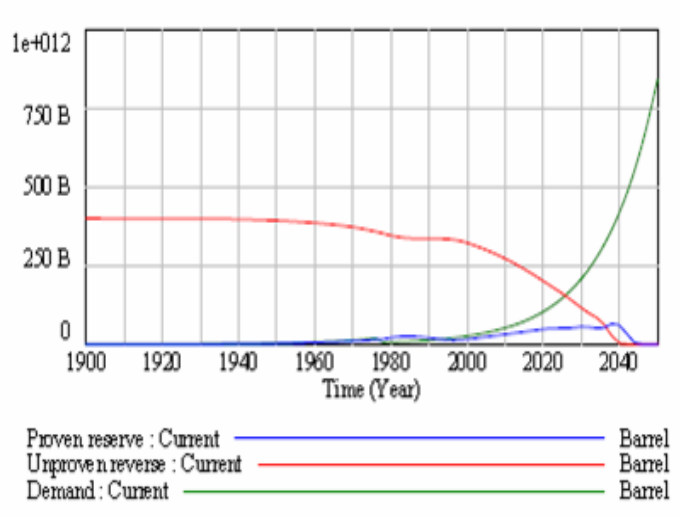

Figure 11. Model results based on Table 2 assumptions

From Figure 8, it can be seen that the cost of oil exploration remains approximately constant until 2020 because the undiscovered resources have not changed significantly. After that, the cost of exploration increases sharply. Consequently, since the price is entirely dependent on the cost of exploration, the conditions related to it are similar to those for the cost of exploration. Regarding the sales rate, it is observed that the sales increase until 2040 and decrease after 2040 due to the depletion of discovered reserves, gradually approaching zero.

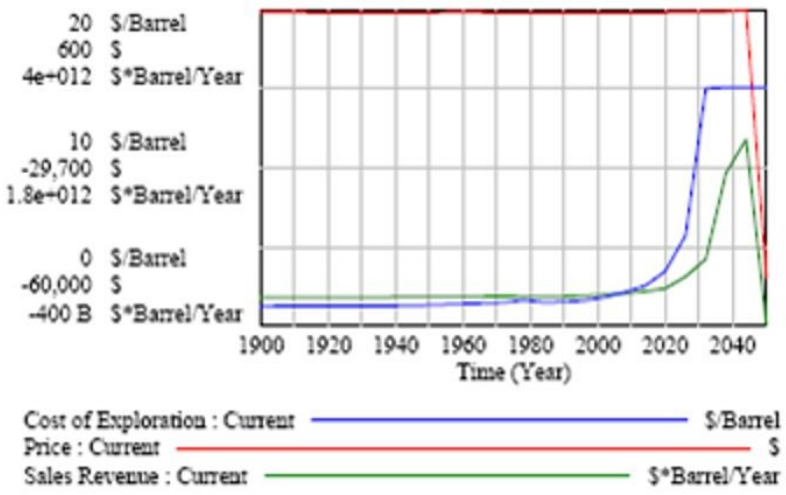

Figure 12. Some other model variables based on Table 2 assumptions

As can be observed from Figure 9, the effective investment is increasing until it reaches its maximum value in 2045. After that, due to the depletion of undiscovered reserves and the consequent decrease in sales, the investment decreases. As a result, this will also lead to a decrease in effective investment. Regarding the discovery rate, an upward trend was initially observed until 1978, when it decreased due to a decrease in investment caused by an increase

in the PRR/DPRR ratio. Investment in exploration follows a similar pattern that is discussed in the analysis of effective investment.

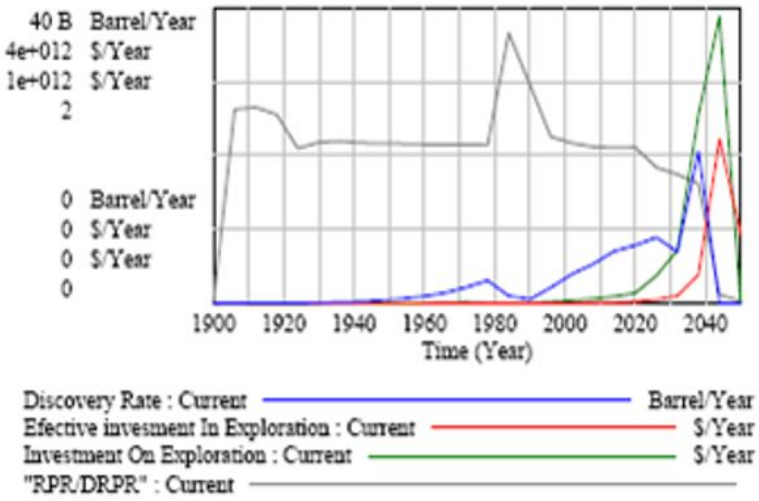

Figure 13. Analysis of some other model variables based on Table 2 assumptions

4. Model sensitivity analysis

In order to analyze the sensitivity of the model, the initial value of the Unproven Reserve variable has been decreased from 400 trillion to 300 trillion. Figure 10 shows the Unproven Reserve, Proven Reserve, and Demand variables. The Unproven Reserve variable starts decreasing earlier than before and reaches depletion about ten years earlier.

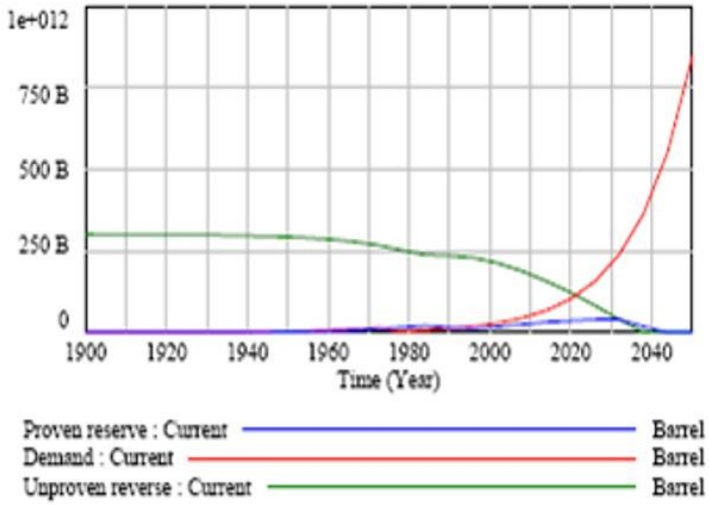

Figure 14. Sensitivity analysis of discovered reserves, demand, and undiscovered reserves variables

The sensitivity of the behavior of the Cost of Exploration, Price, and Sales Revenue variables has been analyzed. This analysis shows that these variables will exhibit behavior similar to the previous case (Figure 11).

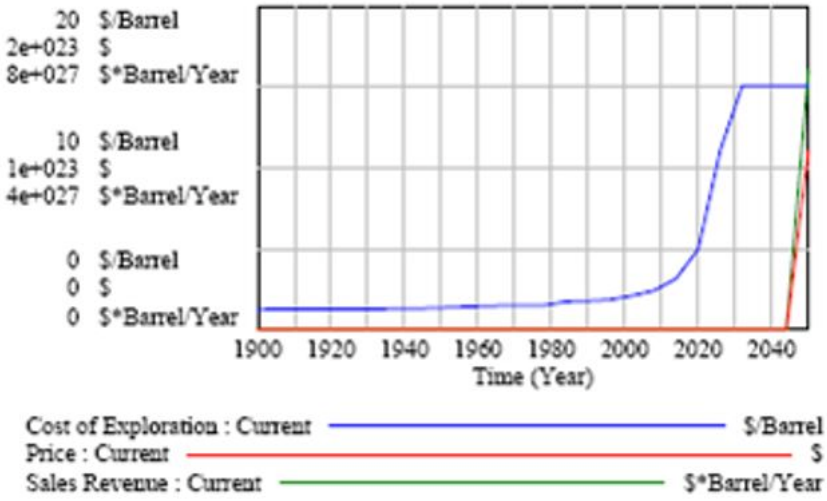

Figure 15. Sensitivity analysis of exploration cost, price, and sales revenue variables

In Figure 12, the Discovery Rate, Effective Investment in Exploration, Investment in Exploration, and RPR/DRPR variables are subjected to sensitivity analysis. Here, too, it can be observed that the variables' behavior does not differ significantly from the previous case.

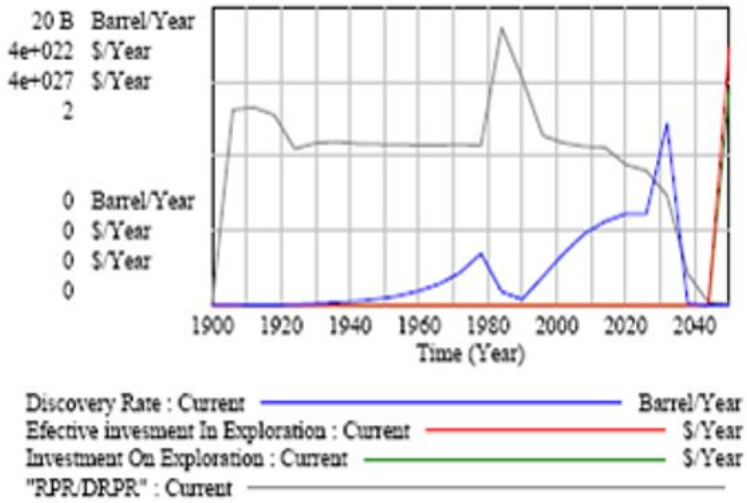

Figure 16. Sensitivity analysis of discovery rate, effective investment in exploration, investment in exploration, and RPR/DRPR ratio variables

Now, to implement other policies, the potential demand decreased from 7% to 2% starting from 1978. Figure 13 shows that by decreasing the demand growth rate, the utilization of reserves decreases, which will result in better utilization of the reserves and their depletion at a later time.

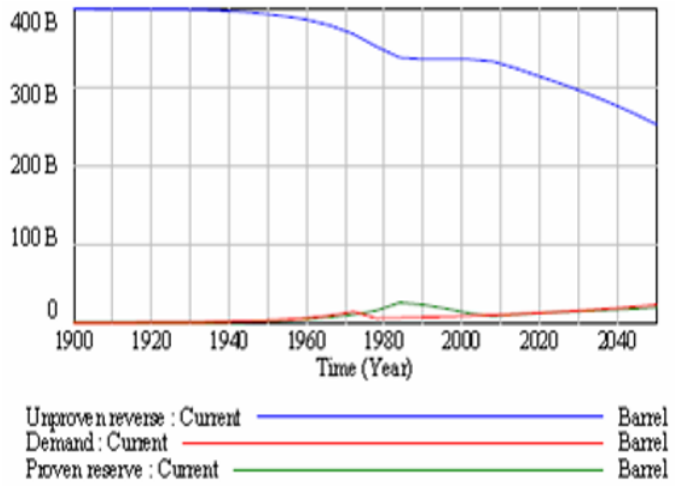

Figure 17. Variable behavior with implementation of new policy

Figure 14 shows the behavior of variables such as exploration cost, price, and sales revenue under the new scenario. It is noteworthy that despite the fluctuations observed in these variables, they ultimately increase in an upward trend.

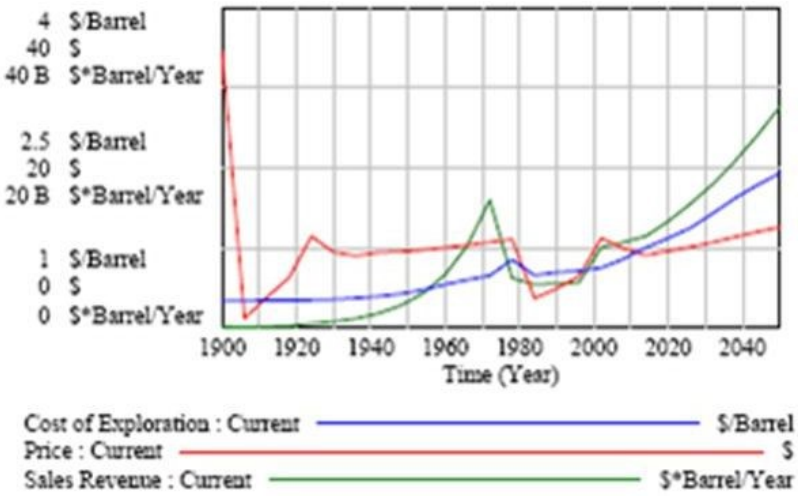

Figure 18. Variable behavior with implementation of new policy

Figure 15 analyses the behavior of the remaining variables under the new scenario.

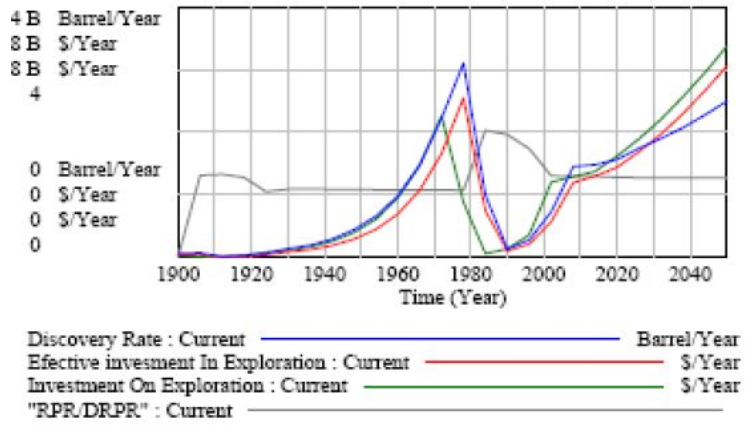

Figure 19. Variable behavior with implementation of new policy

The policy where the government covers 25% of the exploration costs from 1982 onwards has been examined. In this case, the equation for the Cost of Exploration becomes IF THEN ELSE (Time<1982, Graph in Figure 16 FURR), 0.75*Graph in Figure 16 (FURR)), and the results are shown in Figure 16 and Figure 17.

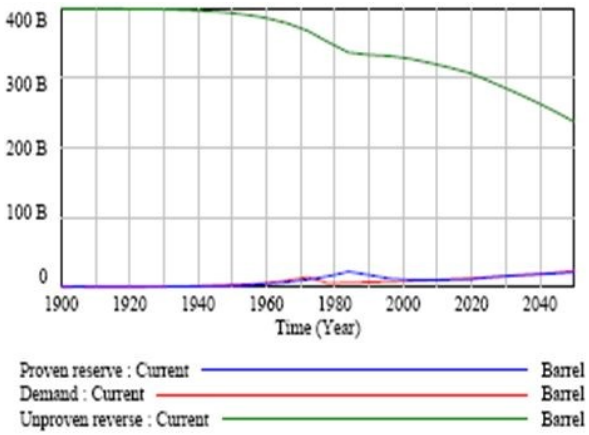

Figure 20. Variable behavior with government participation in exploration

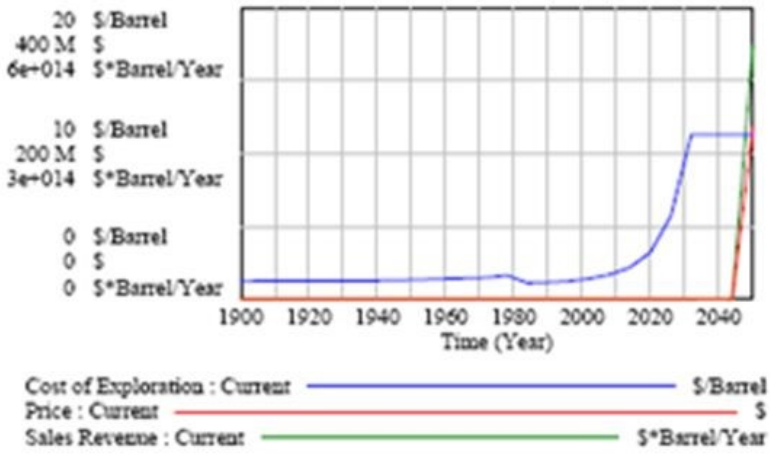

Figure 21. Variable behavior with government participation in exploration

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Under these conditions, with the government's intervention, the extraction cost, which had imposed self-sustaining conditions, decreases, and the extraction rate increases. Consequently, the discovered reserves will increase, and the reserve-to-consumption ratio will increase, naturally leading to a decrease in price and a downward trend in investment.

5. Conclusion and recommendation for future reserech

There is no doubt that oil, this God-given resource, is depleting. From the results of this research, the need to review the macro policies in the areas of exploration, extraction, and consumption emerges. Greater focus on shared oil-rich regions, presentation of an optimal consumption pattern, changing the fuel preferences of factories and industries to non-fossil fuels, and greater private sector participation in exploration and production alongside proper consumption management can temporarily save countries from the potential crisis facing this industry and lead them to calmer shores.

In this paper, numerous criteria and indicators were proposed to evaluate the best possible scenario. Statistics show that OECD member countries, especially the United States, have become more dependent on crude oil compared to past decades, and their vulnerability to oil shocks in the oil production and supply market has increased. Therefore, adopting policies that ensure stability in the operational program of exploration, extraction, and supply of this valuable product, along with optimal consumption management and the provision of alternative fuels, is a measure that delaying it will incur significant costs.

Due to the sensitivity and strategic nature of planning in the oil exploration and extraction industry, it was difficult to access and provide reliable statistics.

- The expectations and demands of the stakeholders were different and wide.
- Due to the presence of some qualitative variables and the lack of reliable sources, it was challenging to adjust the formulation and dynamic equations

As future research:

- It is suggested that through other forecasting techniques, such as the time series model, econometric model, judgmental forecasting model, and Delphi method, the results should be examined and compared.
- According to the conditions and time requirements, new scenarios should be added and analyzed.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Systems Thinking in the Circular Economy: An Integrative Literature Review

Nahid Entezarian[a], Mohammad Mehraeen[a*]

[a] *Department of Management, Faculty of Economics and Administrative Sciences, Ferdowsi University of Mashhad, Mashhad, Iran.*

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ABSTRACT

In this integrative review, the concept of the Circular Economy (CE) is extensively analyzed from the perspective of Systems Thinking (ST) to gain insights into the circular economy. Seventy-two articles from Scopus and Web of Science databases were reviewed to gain a better understanding of the ambivalent nature of circular economy and systems thinking. The main objective of this study is to provide a clear understanding of the circular economy concept through the lens of systems thinking. Therefore, a thematic framework is presented that synthesizes the literature in a tangible form for researchers, practitioners, and policymakers. This review contributes to a better understanding of the circular economy as a complex and dynamic system. It highlights the interdependencies that can arise in the circular economy and emphasizes the need for holistic and systemic approaches to address these challenges. Through this integrative review, six systems thinking applications in the CE are identified, including Stakeholder engagement in decision-making, innovation, and deep transformational change, implementation of circular business models, life cycle management optimization through better resource management, supply chain optimization and reduced unintended consequences and designing sustainable products. This paper contributes to the existing body of knowledge by identifying future research gaps and opportunities to advance in this field of study consistently. It provides a valuable resource for researchers, practitioners, and policymakers seeking to advance the circular economy agenda.

Keywords

Circular economy (CE), Systems thinking (ST), Integrative review, Sustainability.

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*Corresponding author
Email: Mehraeen@um.ac.ir

1. Introduction

The concept of the Circular Economy (CE) is an innovative approach to economic systems that aims to replace the current linear system of production by focusing on redesigning systems and creating closed-loop cycles (Murray et al., 2017). This concept has the potential to develop more sustainable business practices that reduce the negative environmental and social impacts of the current business-as-usual scenario (Ghisellini et al., 2016). By implementing CE, significant changes can be made to the way products are designed, produced, used, and brought back into circulation.

The CE is the most recent effort in academic, governmental, and industrial sectors to tackle the environmental strain resulting from human-made mass surpassing all living biomass (Elhacham et al., 2020). However, the CE is distinctive in that it promotes regenerative thinking and design (Burke et al., 2023). It is described as a system that focuses on minimizing resource input and waste, emissions, and energy leakage by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2017).

At the core of the CE are various circularity strategies, also known as value retention strategies or principles, typically categorized within different frameworks denoted by the letter "R". These frameworks range from the basic 3Rs of "reduce, reuse, and recycle" to the more extensive 10Rs of "refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, recover, and remine" (Reike et al., 2018). These strategies for retaining value are not mutually exclusive and can be combined to reduce, delay, or eliminate resource loops (Bocken et al., 2016).

CE involves two main cycles: the technical cycle and the biological cycle of products and materials (Jabbour et al., 2019). The technical cycle is enhanced by extending the lifespan of products, promoting ownership sharing, minimizing value loss, and utilizing advanced technologies (Huynh and Rasmussen, 2021). In the biological cycle, CE aims to preserve biomass value through recycling, shifting to renewable resources, and prolonging the lifespan of bioproducts to reduce waste (Montag, 2023). This approach aims to optimize resource efficiency, increase material utility, and reduce greenhouse gas emissions.

As a result, the implementation of a CE necessitates a holistic approach that spans different levels and incorporates diverse practices across the entire product life cycle (Iacovidou et al., 2021). Consequently, technical solutions need to be improved. They must be supplemented with new business models, essential supply chains, and conducive systemic conditions in order to facilitate the transition to a CE (Ellen MacArthur Foundation, 2022). While terms like stocks,

flows, feedback loops, and leverage points are commonly used in CE literature, there have been few studies that have attempted to clarify the meaning of systems thinking in this context.

Systems thinking is a methodology suggested for organizing and conceptualizing the various components of the CE (Aggesund, 2018). The concept of CE is fragmented, lacking a coherent framework, requiring exploration from a systems perspective for integrating ideas and bridging gaps in theory and practice. System thinking, as a participatory approach, can blend diverse perspectives and address social aspects in CE literature. Systems thinking is the scientific approach to making dependable predictions about behavior by developing an understanding of the underlying structure of a system. It enables us to gain a better understanding and predict the consequences of our decisions across different sectors, economic actors, time, and space (Probst and Bassi, 2017). Systems thinking is well-suited for conceptualizing the CE because it deals with complicated and complex systems.

Various perspectives exist on how the CE is conceptualized and illustrated in academic literature (Kirchherr et al., 2023). In order to develop a cohesive framework and bring clarity to the subject, this article utilizes an integrative research approach to knowledge construction. This integrative literature review critically evaluates and combines key literature on the subject cohesively, resulting in the creation of fresh frameworks and viewpoints (Dwertmann and van Knippenberg, 2021; Torraco, 2016). It is especially suitable when research pertaining to a specific topic is scattered across various fields and has not been comprehensively examined and merged (Elsbach and Van Knippenberg, 2020). The primary objective of the integrative review is to bridge different communities of practice studying the same topic (Cronin and George, 2023). Integrative reviews can be applied to both emerging and more established research fields and although they are a pertinent approach in business research, their utilization is still limited (Snyder, 2019). Furthermore, "the integrative review is most useful when different communities of practice appear to be working independently, and their research could be enhanced by synthesizing their findings" (Cronin and George, 2023). The present condition of literature concerning the CE is highly conducive to this approach. Despite a growing number of publications on the subject, research on the CE remains a relatively nascent field (Alcalde-Calonge, 2022). As a fragmented concept lacking coherence, the CE concept requires further exploration to facilitate the integration of varied ideas and perspectives (Hassan and Faggian, 2023). This intricacy emphasizes the necessity for a cohesive comprehension of current and evolving subjects (De Angelis, 2022). This article depends on the utilization of key academic

sources to consolidate the current state of knowledge. In order to improve conceptual clarity, this article examines the framework and applications of systemic thinking in the CE.

The paper is organized as follows: Section 2 describes the theoretical background within CE systems and the foundations for applying systems thinking modeling to investigate CE research in the field. Section 3 outlines the research methodology employed. Section 4 contains results, relevant discussions, and contributions. Finally, section 5 delineates the conclusion and emerging research avenues.

2. Theoretical background

2.1. Circular economy (CE)

The idea of CE has gained importance among policymakers as a vital approach to dealing with sustainability issues (Korhonen et al., 2018; Yu et al., 2022). The CE is defined by the United Nations Environment Program (UNEP) as an economy that aims to reduce resource consumption and waste generation by reusing and recycling wastes throughout the production, distribution, and consumption processes (UNEP, 2011). Developed and industrialized countries, like Japan, were among the first to adopt the CE as an economic development strategy, particularly within the industrial sector, with the goal of minimizing waste generation in the production process and reducing imports (UNEP, 2011).

The CE aims to shift economic systems away from the traditional take-make-waste approach towards more efficient and regenerative processes. It includes measures such as improving product durability, implementing green public procurement, extending producer responsibility, and enhancing materials recovery (Isenhour et al., 2023). It is seen as a promising solution to urgent environmental challenges such as climate change, biodiversity loss, and resource depletion. The CE seeks to reduce production and consumption costs while providing significant environmental benefits. Furthermore, it has the potential to improve social and economic advantages, which in turn can help alleviate various pressures on the Earth's resources (Khajuria et al., 2022).

The CE is seen as a new approach to development that analyses consumption, production, and materials management systemically. Consequently, the environmental impacts of waste, social repercussions, and economic outcomes become the pillars of the analysis driving potential investments in the CE (Lehmann et al., 2022).

Given the broad definition of the CE, a wide range of indicators is needed to assess the performance of any CE investment or policy. These indicators include (Bassi et al., 2021;

Topliceanu et al., 2022): (1) Consumption: This indicator focuses on human behavior, such as affluence, culture, and personal preferences for purchasing different products and services. Together with population and economic growth, it determines the total volume of products and materials used in the economy. (2) Production: This indicator considers various production processes across different industries, from early-stage product design to operational efficiency. It assesses how efficiently resources are used and waste is minimized throughout the production chain. (3) Materials Management: This indicator examines how resources and waste are managed throughout their lifecycle, including extraction, manufacturing, use, and disposal. It looks at the efficiency of resource use, recycling rates, and the reduction of waste generation. (4) Social and Environmental Outcomes: These indicators assess the impacts of CE practices on social well-being and environmental quality. They consider the reduction of pollution and resource depletion, as well as the improvement of human health and well-being. (5) Trade: This indicator examines the impact of CE practices on international trade patterns. It considers the potential for new markets and job creation, as well as the implications for global resource flows and supply chains (Bassi et al., 2021; Topliceanu et al., 2022). By considering these indicators, policymakers and investors can evaluate the effectiveness and sustainability of CE initiatives. This comprehensive assessment allows for a holistic understanding of the potential benefits and challenges associated with transitioning to a CE.

A systemic approach is frequently employed to gain a deeper understanding of the intricate causal relationships that exist between these domains. The CE employs systems thinking to design products that are intended to be recycled or reused (Bassi et al., 2021). The difference between a traditional linear economy and a CE is shown in engineering in the image below (Figure 1). Engineering the Circular Life Cycle is a concept in sustainable engineering and design that aims to reduce waste and promote the reuse and recycling of materials throughout the product life cycle. This approach focuses on creating products and systems that minimize environmental impact and contribute to a CE.

Implementing a CE requires knowledge integration and systems thinking across different sectors, such as agriculture, industrial production, and materials management, as well as involving societal and economic stakeholders like firms, consumers, and institutions. In order to assess the effectiveness of CE interventions, all three dimensions of development (society, economy, and environment) must be considered, as well as the assessment of results over time, encompassing short-, medium-, and long-term effects (Bassi et al., 2021).

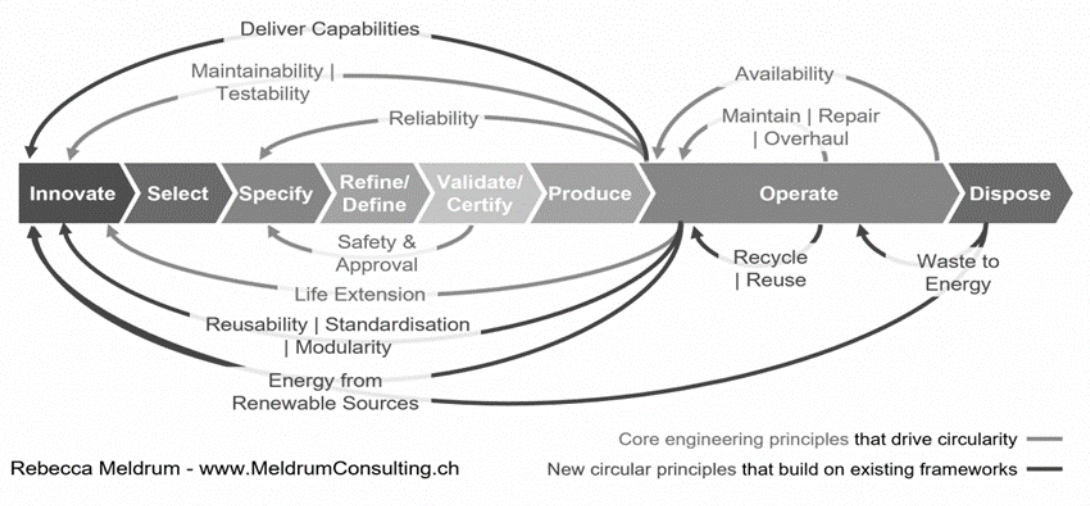

Figure 22. Engineering the circular life cycle. source: Meldrum (2023)

2.2. Systems thinking (ST) in CE

Systems thinking is integrated into various theories, ontologies, concepts, and tools used across disciplines to tackle the challenges of achieving changes and transitioning towards a circular and sustainable future. Systems, which are often described as more than the mere sum of their parts consist of elements, relationships, structure, and purpose. Systems thinking involves comprehensively approaching and analyzing the components of a system, understanding their interconnections and structure, and studying how systems operate over time, all within the broader context of larger systems (Ratinen and Linnanen, 2022).

The economy is a system in which individuals utilize resources to engage in activities that create value. Individuals exchange goods and services in markets with the goal of maximizing overall utility for society. However, based on its behavior, a crucial function of the economy is to expand and grow. This growth is often desired to occur at a consistent or even accelerating rate, typically following an exponential pattern. Economic growth is assessed through the measurement of the gross domestic product (GDP), serving as the principal metric for evaluating the economy (Robinson, 2022).

Systems thinking is considered important for fully understanding the causes of problems and potential solutions (Whalen et al., 2018). It allows for the analysis of a system and the identification of ways to change it to meet the needs of a specific group. While the literature recognizes the need for systems thinking in designing for a CE, it often only calls for holistic thinking without providing specific methods. The varied origins of the CE concept, its present role in comprehensive economic discussions, its sustainability context, and the challenges in implementing it due to its current narrow approaches highlight the necessity for a

comprehensive examination of the CE concept within systems. The relevance of Systems Thinking approaches to CE lies in the fact that CE is based on systems ecology. These approaches enable a more thorough examination of the intricate and dynamic aspects of contemporary production, distribution, and consumption processes. It facilitates the redirection of CE objectives towards integrated socio-ecological goals for sustainable development (Hassan and Faggian, 2023). However, there are several systems thinking methods that can be useful in the context of designing for a CE. These include the Circularity Thinking method, which helps explore current and future circular systems; the Circularity Compass, which identifies wastes in the system (Blomsma and Brennan, 2018); and the Circularity Grid, which generates an understanding of the relationships among different parts of the system.

3. Methodology

This article utilizes an integrative review method, which is frequently employed to address new and emerging subjects that necessitate a thorough grasp of current empirical and theoretical literature (Torraco, 2016). The integrative literature review method analyses and synthesizes the key concepts and arguments that are put forward in academic or scholarly writings to generate new insights and identify future research directions (Cronin and George, 2023). In this study, the integrative literature review approach is used to critique and synthesize insights from the fields of CE and systems thinking. This approach to CE allows for the development of new perspectives, theories, and research directions. The review was conducted following a systematic process of planning, execution, and analysis.

3.1. Planning

The first step of the review involved creating a map of the literature to clarify the main concepts of CE and systems thinking and how they are related. A primary literature search was done to identify keywords and confirm the gap in the literature. During the initial planning stage, specific keywords were carefully established in alignment with the objectives of the research, which aimed to assess the extent of understanding and implementation of CE practices and strategies using a systems thinking approach. Two distinct sets of terms were identified to guarantee the utmost relevance: "CE" and phrases associated with "systems thinking". This meticulous process facilitated the selection of pertinent literature for the comprehensive review. The inquiry was designed to systematically search for specific terms within the titles, abstracts, and keywords of scholarly publications. These terms were meticulously selected to encompass

a broad spectrum of the most pertinent literature pertaining to the application of systems thinking within the realm of CE. It is essential to acknowledge that certain materials may have been inadvertently omitted from this review. The titles, abstracts, and, in some cases, the entire text of the resulting sample were assessed to determine their relevance according to the criteria outlined in Table 1.

Table 24. The criteria utilized for the screening process of the articles

Database	Scopus, Web of Science, Google Scholar
Field	Title, keywords, abstracts
Search string	("circular economy" OR " CE") AND ("systems thinking" OR "ST")
Type of publication	Journal articles, book chapters, conference proceedings
Language	English
Period	between 2013 to 2024

Thus, this integrative review does not purport to offer a comprehensive analysis but instead aims to present a representative sample of the existing knowledge concerning the implementation of CE with a systems thinking approach at a specific juncture in time. The chosen terms were employed in a supplement fashion, ensuring that each contributed to the overall pool of publications retrieved in the search results.

3.2. Execution

In the execution stage, multiple criteria were established to select the most suitable papers for the study. The study utilized two databases, Scopus and Web of Science, as well as the Google Scholar search engine, to ensure thorough and high-quality coverage. The search criteria were designed to encompass journal articles and conference proceedings in English. During the selection process, duplicate entries were removed. The titles, abstracts, and, if necessary, the full texts of articles were assessed to identify those that could best contribute to the study and offer insights into the connections between CE and systems thinking based on the outlined criteria. After conducting a comprehensive search and screening process,72 scientific papers between 2013 and 2024 were selected for this research. These papers provide insights into CE and systems thinking practices and their interrelationships. They include Qualitative and quantitative studies on CE functions and strategies examined with a systems thinking approach, as well as studies that mention CE practices and strategies for systems thinking, even if systems thinking is not the main focus of the studies (Figure 2).

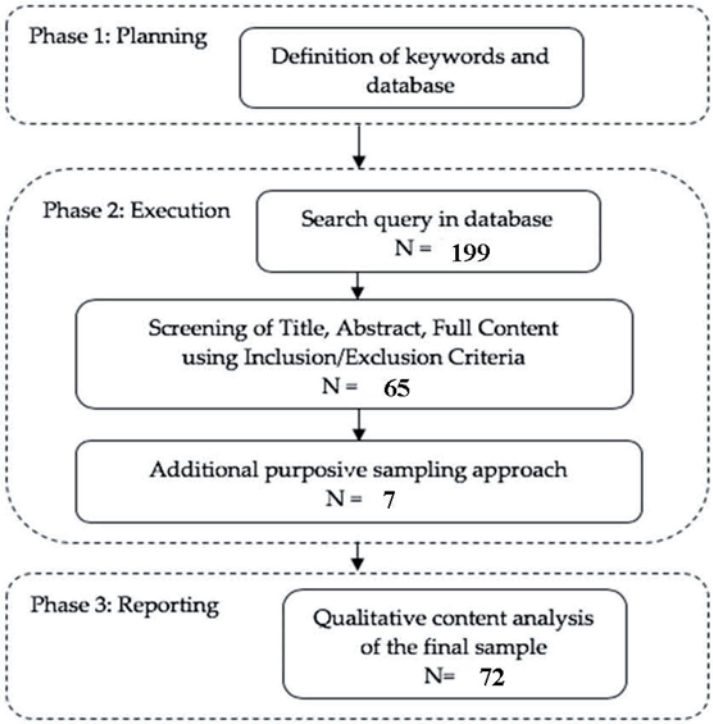

Figure 23. Summary of the methodological approach based on Tranfield et al. (2003)

3.3. Analysis

This research employed a qualitative content analysis method (Becker et al., 2012) to analyze selected documents. This approach aimed to identify key themes present in the literature. The analysis process involved reading and rewording the articles, as well as inductively coding their contents. The codes derived from the analysis were then reviewed for similarities and grouped into categories. This iterative process allowed the researchers to identify larger patterns by continuously moving between the data and emerging ideas. Afterward, the different categories were combined into general themes (Table 2), which were used to analyze and, in detail, understand how systems thinking is connected to a CE.

4. Result and discussion

The trend of article publication shows that the number of articles published in this field has been on an upward trend from 2013 to 2023 year. This evolution, mainly in recent years, shows the importance of this topic in the literature and has become an emerging trend (Figure 3).

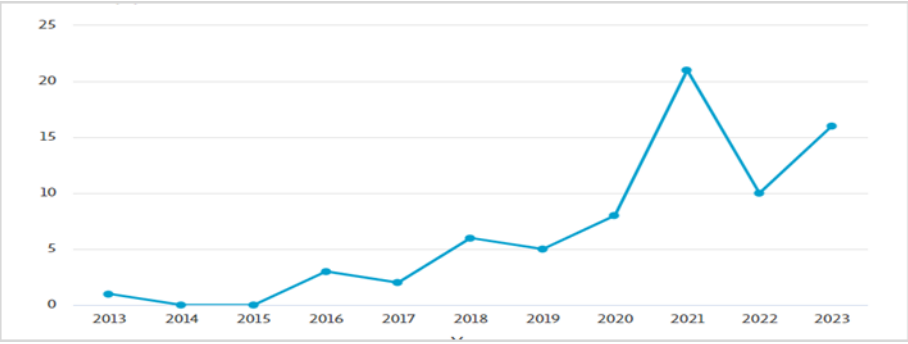

Figure 24. Distribution of articles from 2013 to 2023 year

A first look at the dispersion of the papers among many different subjects shows that although the query is focused on the terms "systems thinking" and "circular economy", papers appeared in a very wide range of subjects. The papers mainly examine CE in the domains of Environmental Science, Engineering, Social Sciences, and Energy. Figure 4 shows the distribution of articles by subject area in the 72 papers collected.

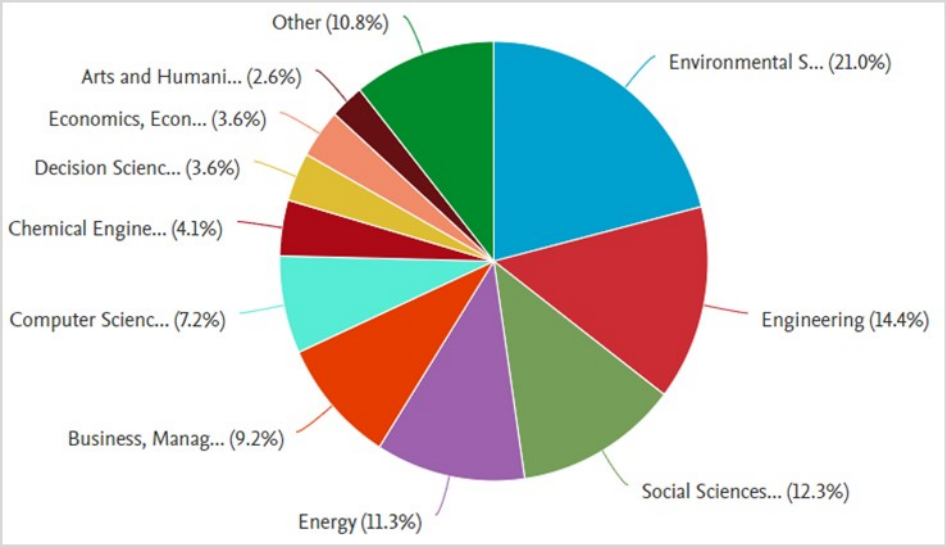

Figure 25. Distribution of articles from document by subject area

This paper introduces a new method by combining the concepts of CE and systems thinking to examine their connections. Systems thinking is an important approach for implementing CE practices. The paper reviews existing research and identifies six applications for using systems thinking in a CE. These applications are designed to identify underlying causes, understand the dynamics of the system, create product-service systems, manage the life cycle of products optimally through systems, enhance risk management, and promote sustainability (Table 2 and Figure 5).

Table 25. Applications for systems thinking in a CE. Source: authors

Approach	Attribute	(Expected) Outcome	Reference
Stakeholder engagement in decision	Systems thinking encourages collaboration and cooperation among various stakeholders in the circular economy. By involving stakeholders such as manufacturers, consumers, policymakers, and waste management organizations in the decision-making process, systems thinking can facilitate the adoption of circular practices and the co-creation of sustainable solutions.	Holistic approach and Understanding system dynamics, The use of Multiple stakeholders in decisions, Considering relationships between different factors (processes, values, and stakeholders)	Véliz et al.(2023), Demartini et al.(2023), Brinton et al.(2023), AlMashaqbeh & MuniveHernandez (2023), Ghufran et al.(2022), Esfandabadi et al.(2022), Robinson (2022), Bassi et al.(2021), Balanay & Halog (2021), Fanta et al.(2021),Termeer & Metze(2019), Esfandabadi & Ranjbari(2023)
Innovation and Deep transformational change	Systems thinking encourages a holistic and integrated approach to innovation in the circular economy. By considering the broader system and its dynamics, systems thinking can help identify opportunities for technological advancements, business model innovation, and systemic change toward a more circular economy.	Fundamental changes to production and consumption systems, The use of ICT to enable the transition towards circular economy, Environmental protection	Blomsma and Brennan (2023), Royle & Gibson(2023), Whitehill et al.(2022), Harder et al.(2022), Russo & van Timmeren(2022), Žilinskaitė et al.(2021), Iacovidou et al.(2021), Iida et al.(2021), Freire(2020), Giraldo Nohra et al.(2020), Chen (2020), Termeer & Metze(2019), Nogueira et al.(2019), Hall & Velez-Colby(2018), Gorissen Vrancken & Manshoven (2016)
Implementation of Circular business models	Systems thinking supports the development and implementation of circular business models. By understanding the broader system in which a business operates, including its stakeholders and external environment, systems thinking can help identify innovative ways to design products, offer services, and manage resources circularly.	Business model configuration, Resource decoupling, Creating a market for recyclable products. Collaboration between multiple stakeholders in the design and operation of the reverse logistics system	Ding et al.(2023), Migliaccio et al.(2023), Hidalgo-Carvajal et al.(2023), Yhdego(2021), Lugnet & Larsson (2021), Waring & Liyanage(2021), Dan & Østergaard(2021), Bakırlıoğlu et al.(2021), Mendoza et al.(2017), Lobos(2017), Pollard et al.(2016)
Life cycle management optimization through Better resource	Systems thinking helps in understanding the entire lifecycle of a product or service, from its production to its disposal. By considering the inputs, processes, outputs, and impacts at each stage, businesses and policymakers can identify opportunities for waste reduction, resource efficiency, and circularity.	Reducing natural resource over-exploitation, Preserving and increasing the value of resources used in production and consumption, using renewable resources, recycling materials, and reducing energy consumption	Anastasiades et al. (2023), Demartini et al.(2023), Russell et al. (2023), Fassio & Chirilli (2023), Friedman (2023), Ng & Yang(2023), Keßler et al.(2021), Roy et al.(2021), Tong et al.(2021), Savolainen et al.(2020), Mohan & Katakojwala(2021), Somoza-Tornos et al.(2020), Whalen & Whalen(2018), Balanay & Halog(2016), Webster (2013)
Supply chain optimization and reduced unintended consequences	Systems thinking enables businesses to identify unintended consequences, barriers, and opportunities for collaboration. By considering the interconnections and interdependencies between suppliers, manufacturers, distributors, and consumers, systems thinking can help optimize the supply chain, reduce waste, and improve resource utilization.	Reducing supply chain risks, The use of flexible developing models, Extended decision making and functional failure mode and effects analysis (FMEA) models	AlMashaqbeh & Munive-Hernandez (2023) Shafik & Case(2022) Barnabè & Nazir(2022) Blomsma &Brennan(2018)
Designing sustainable products	Systemic thinking can be used to design durable, repairable, and recyclable products. It can help reduce waste, promote a circular economy, and increase sustainability in product production and consumption.	Sustainable decisions in the circular economy, Sustainable mass production, The incorporation of Sustainable Development Goals (SDGs) into corporate sustainability strategies	Maher et al.(2023), Shams Esfandabadi & Ranjbari(2023), Dokter et al.(2022), Nyakudya & Ayomoh(2022), El-Khawad et al.(2022), Metic & Pigosso(2022), Ghufran et al.,(2022), Allen et al.(2021), Keßler et al.(2021), Stuiver & O'hara(2021), Chen (2021), Sumter et al.(2021), Allen & Tomoaia-Cotisel(2021), Cho (2021), Lu & Halog(2020), Sumter et al.(2020), Fassio & Tecco(2019), Hussain & Jahanzaib(2018), Perey et al.(2018), Poberezhna(2018)

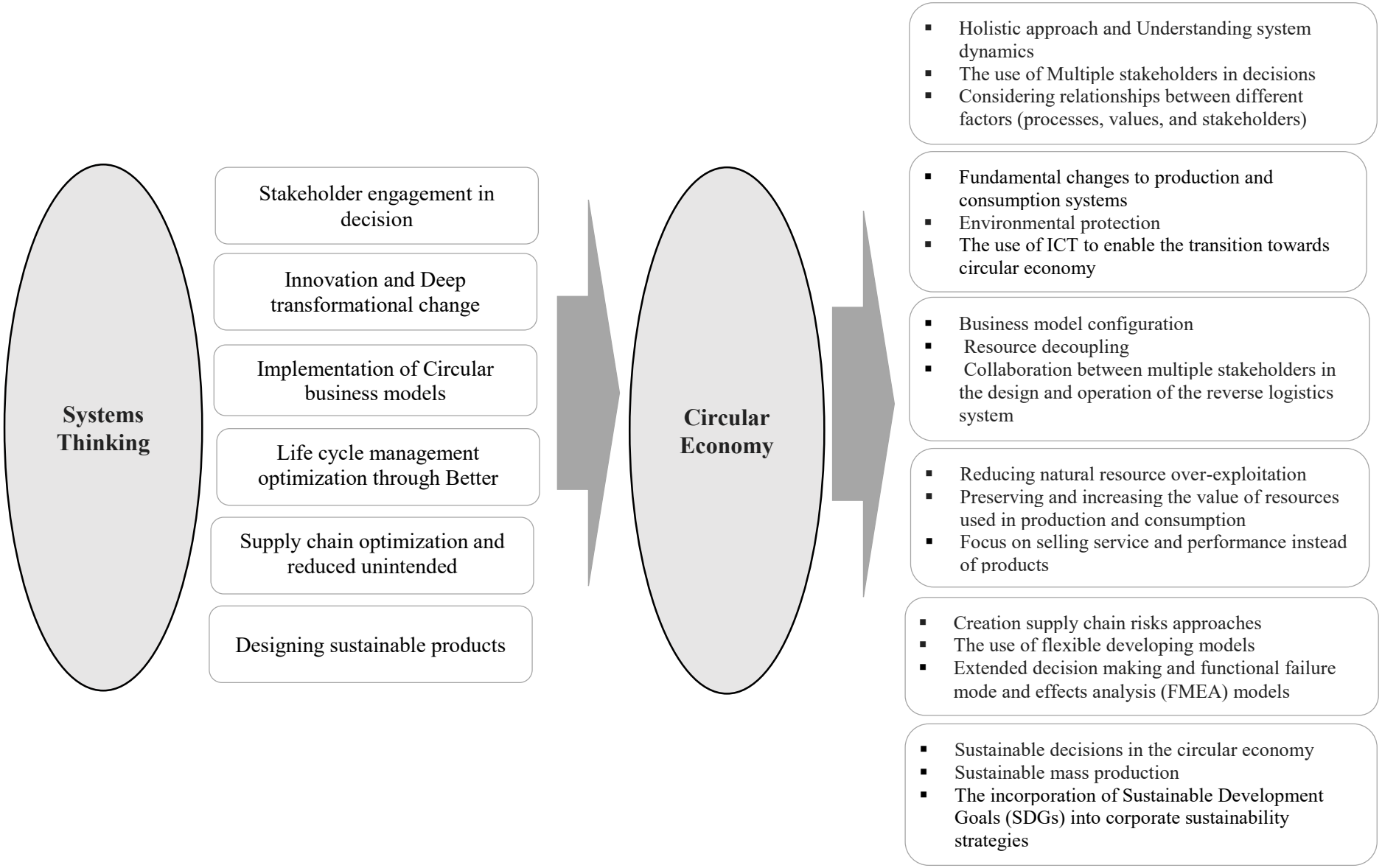

Figure 26. A model for utilizing systems thinking within the context of a CE.

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This combined knowledge improves comprehension of systems thinking within a CE and lays the groundwork for additional research in this field. However, the transition signifies a substantial reorganization of the current CE, emphasizing greater integration and cooperation with systems thinking (Ghafoor et al., 2023).

- Systems thinking is a way of understanding complex systems by considering the relationships between their parts and how they interact with each other. The impact of systems thinking on the CE is significant, as discussed below:

- Systems thinking provides a holistic approach to understanding the dynamics between processes, values, and stakeholders in the CE. It encourages collaboration and stakeholder engagement in the CE transition. By involving diverse stakeholders and considering their perspectives, decision-makers can develop more inclusive and effective CE strategies. It helps to identify potential barriers to implementation and develop strategies to overcome them.

- Systems thinking helps in understanding the interconnections and interdependencies between various components and processes within the CE. This understanding is crucial for designing effective circular systems and identifying potential bottlenecks or areas for improvement.

- Systems thinking helps identify feedback loops within the CE, where the outputs of one process or component can become inputs for another. By understanding these feedback loops, decision-makers can optimize resource flows and minimize waste generation. Systems thinking also helps develop better solutions for the CE. By considering the interactions between different parts of the system, it is possible to design products and processes that are more efficient, sustainable, and resilient.

- The CE is a complex system with many interrelated parts. Systems thinking provides a useful means of cutting through this complexity and focusing on the dynamics between processes, values, and stakeholders. Systems thinking allows for the analysis of system dynamics, including the behavior of stocks and flows, delays, and feedback mechanisms. This analysis helps in predicting the long-term effects of CE interventions and designing strategies for system resilience and adaptability.

- A CE involves complex system operations, such as product-service systems, remanufacturing, and repair. Systems thinking can help design these systems to be more efficient and effective.

- Systems thinking helps define the boundaries of the CE system and understand its interactions with the broader socio-economic and environmental systems. This understanding enables a holistic approach to CE implementation and prevents unintended consequences or

externalities. By considering different perspectives and scenarios, responses can be broadened, and risks can be prevented. Also, it can help businesses better navigate system risks, barriers, and opportunities and can lead to more sustainable and profitable business practices.

- CE practices require deep transformational change in the way we produce, consume, and dispose of goods and services. Systems thinking can help promote this change by identifying the underlying causes of problems and developing solutions that address them. It provides a framework for systemic innovation in the CE. It helps identify leverage points for intervention, explore alternative system configurations, and design novel business models and technologies that support circularity.

- A key objective of a circular economy is to cycle products and materials through systems that are regenerative and restorative. Systems thinking can help identify the most effective ways to achieve this objective. Applying systems thinking to circular economy practices can help unlock the sustainability potential of circular processes. It can help progress the sustainability agenda and lead to a more sustainable future.

5. Conclusions

The CE is a topic that is widely discussed worldwide. Currently, most discussions focus on the importance of achieving a CE and the associated benefits. The CE is a concept that aims to create a sustainable and regenerative economic system by minimizing waste and maximizing resource efficiency. Systems thinking, on the other hand, is an approach that considers the interconnections and interdependencies between various components of a system. This integrated literature review explores the applications of systems thinking in the context of the CE. The review examines various studies and research papers that highlight the benefits of applying systems thinking in the CE.

This study identifies several key applications of systems thinking in the CE that must be taken into account to facilitate the transition towards a CE, namely, Stakeholder engagement in decision-making, innovation and deep transformational change, implementation of circular business models, life cycle management optimization through Better resource management, supply chain optimization and reduced unintended consequences and designing sustainable products. Firstly, this study emphasizes the importance of considering the entire lifecycle of a product or service, from production to disposal. By adopting a systems thinking approach, businesses and policymakers can identify opportunities to reduce waste and improve resource efficiency at every stage of the product lifecycle. Systems thinking helps in identifying

feedback loops within the CE, where the outputs of one process or component can become inputs for another. By understanding these feedback loops, decision-makers can optimize resource flows and minimize waste generation. Secondly, this study highlights the need for collaboration and cooperation between different stakeholders in the CE. Systems thinking encourages a holistic view of the system, which can help identify potential synergies and opportunities for collaboration. By involving various stakeholders, such as manufacturers, consumers, and waste management organizations, in the decision-making process, systems thinking can facilitate the implementation of CE practices. Systems thinking encourages collaboration and stakeholder engagement in the CE transition.

Furthermore, the review emphasizes the role of systems thinking in addressing the complexity and uncertainty associated with the CE. The CE involves multiple interconnected systems, including supply chains, waste management systems, and consumer behavior. Systems thinking provides a framework for understanding and managing these complex systems, enabling businesses and policymakers to make informed decisions and anticipate potential challenges. Systems thinking helps in understanding the interconnections and interdependencies between various components and processes within the CE. This understanding is crucial for designing effective circular systems and identifying potential bottlenecks or areas for improvement.

This comprehensive approach provides a practical method for navigating complex systems. It highlights the connections between processes, values, and individuals within the value chain, as well as their dependence on cultural, spatial, and temporal factors. Adopting a systems thinking-based approach can develop the necessary skills to recognize and comprehend Stable circular trends, thereby facilitating forward-thinking and investment in sustainable transitions. In turn, this approach can assist in prioritizing and transforming our current practices, expediting the transition to a CE in a sustainable way. Systems thinking is a crucial method for comprehending and advancing the CE. There are numerous significant avenues for future research in this developing field that could offer fresh perspectives and increase awareness regarding the demands of this emerging phenomenon. Therefore, it is necessary to conduct research in order to develop more comprehensive frameworks for understanding CE systems, which include examining the interactions between various processes, stakeholders, and values. Future studies should also take into account factors that can be improved through a systems thinking approach, such as resource recovery systems and the promotion of more effective CE strategies at the local level. Additionally, research should explore the development and adoption

of circular business models, the role of systems thinking in identifying the root causes of CE challenges and implementing better solutions, and the potential of systems thinking to encourage the development of more sustainable products and services. In summary, future research on the CE using a systems thinking approach should focus on developing more comprehensive and effective methods for understanding and promoting circularity in various scales and contexts.

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Development of Iran's Electricity Transmission Capacity, Based on Forecasting the Demand Trend Using the System Dynamics Approach

Mohammad Taghi Farahnak[a], Mohammad Ali Afshar Kazemi[a], Ali Mohaghar[b*], Mohammad Ali Keramati[a]

[a] *Department of Industrial Management, Central Tehran Branch, Islamic Azad University, Tehran, Iran.*
[b] *Department of Industrial management, Faculty of Management, University of Tehran, Tehran, Iran.*

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ABSTRACT

This research models and simulates the development of transmission capacity considering electricity supply and demand dynamics. After presenting a causal loop diagram and designing a stock and flow diagram, the model's validity is confirmed using validation methods for system dynamics models. The analysis then proceeds to scenarios for the total electricity demand in Iran. Firstly, the country's electricity demand structure is broken into industrial, household, agricultural, and other sectors. By studying consumption trends in each sector, linear and nonlinear regression are used to predict total electricity demand. Next, three scenarios - optimistic, moderate, and pessimistic - are defined in terms of electricity demand, and the required transmission capacity is calculated and designed for 400, 230, 132, and 63-66 kilovolt substations to cover and meet future electricity demand over twenty years. The research findings over a 20-year horizon indicate that in the moderate scenario, where electricity demand increases by 90 percent, the transmission capacity needs to increase by 106 percent to meet the demand. In the optimistic scenario, where electricity demand increases by 71 percent, the transmission capacity needs to increase by 85 percent. In the pessimistic scenario, where electricity demand increases by 110 percent, the transmission capacity needs to increase by 126 percent.

Keywords

System dynamics, Power transmission capacity, Expected power demand, Power transmission capacity development.

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*Corresponding author
Email: amohaghar@ut.ac.ir

1. Introduction

One of the most significant challenges and problems in the electricity industry that has led to its lack of development is related to reduced investment in the development of the transmission network and the aging of power transmission equipment (Rajabi Mashhadi, 2018). Due to high uncertainty regarding the amount, location, and timing of investments in the transmission sector (Kucuksayacigil and Min, 2021; Strbac et al., 2014), the power transmission system in Iran is constantly faced with challenges in timely investment development due to well-founded reasons, as reported by the Ministry of Energy and the current and past trends (Sha et al., 2018).

Transmission capacities with different ages and their losses, variable electricity demand and supply over time, and the relationship between required capacity and actual capacity, along with other intervening variables, contribute to increasing complexity and uncertainties in understanding the impact of these variables on each other. Additionally, the enforcement of sanctions in Iran has markedly heightened the intricacy of policy formulation in the electricity transmission sector.

Due to the significant impact of numerous parameters and variables in this field, the system dynamics have demonstrated their effectiveness in various economic and social issues and provide suitable capabilities. The prominent features of system dynamics compared to other methods that led to its employment in the current research are as follows:

- The ability to consider bilateral and feedback relationships between variables
- The ability to account for time delays between different variables, such as the delay between investment and capacity development
- The ability for computers to simulate and observe the behavior of key variables over time
- The ability to use the aging chain feature in simulations because the likelihood of capacity retirement is directly related to equipment age, which increases over time
- The ability to define scenarios and observe their effects on the future behavior of influential and key variables.

The primary focus of this study is to develop a model for electricity transmission capacity that incorporates different capacity expansion policies while also taking into account changes in demand. This research aims to address this issue by creating and validating a system dynamics model, designing projected demand scenarios based on historical consumption data from industrial, household, agricultural, and other sectors, and then estimating sustainable transmission capacity growth within the Iranian power grid over the next two decades.

2. Literature review

Long-term planning in expanding the power transmission network provides a systematic and profitable expansion of electrical equipment and facilities to meet the expected energy demand with a reliable degree of certainty (Ude et al., 2019). Researchers have made efforts to propose a scheme to encourage investment in the transmission sector (Contreras et al., 2009). In a study, the impact of tariff policies on the cash flow of the power grid was examined, and an optimization decision-making model for investment was developed (He et al., 2018). Researchers have used system dynamics to model the relationship between investment and electricity transmission capacity, showing that transmission capacity planning can be centralized or decentralized, each having its advantages and disadvantages. Additionally, researchers have simulated the power transmission industry of Colombia using their model (Zambrano et al., 2019).

Furthermore, past studies have shown that most electricity structure analyses have been predominantly focused on the production sector(Dismukes et al., 1998), and the use of system dynamics in this sector of the electricity industry has been inevitable (Dehghan et al., 2021; Monjazeb and Rezaei Movahed, 2019; Sha et al., 2018; Shiu et al., 2023). System dynamics has shown that besides investing in production equipment, investments in research and development (R&D) and efficiency are also crucial. Demand management strategies and reduction, such as increasing the efficiency of consumer equipment, play a prominent role in demand and production sustainability (Qudrat-Ullah, 2013).

With research in Iran, a model for developing the supply sector in the electricity industry considering all technical, technological, economic, and environmental dimensions has been presented. By utilizing this model, a long-term plan for extracting electrical energy supply can be developed. A comparison between the current development trend and a model-based development trend shows that using a system dynamics-based model can lead to economic savings in electricity development (Mohaghar and Najafzadeh, 2017). Another domestic study has proposed a model for investment in developing power distribution capacity. This research suggests a combined method incorporating centralized and decentralized development features. This planning method improves the timing of investments compared to decentralized methods while reducing consumption costs compared to centralized methods (Ahmadvand and Kalantari Hermzi, 2019).

Another factor intensifying the need for increased investment in the electricity industry is related to losses. In Iran, using data from 1383 to 1393, losses have been predicted using both

system dynamics and regression statistical methods, showing that econometric methods provide more accurate estimates than system dynamics models. System dynamics models are more suitable for demonstrating cause-and-effect relationships between variables and the extent of each variable's impact on another. Another study has reviewed the application of system dynamics in the electricity industry (Ahmad et al., 2016).

Also, the utilization of statistical methods and deep learning has been extensively employed in previous research to forecast electricity consumption (Mateo-Barcos et al., 2024; Qureshi et al., 2024; Rao et al., 2023; Meira et al., 2023), and as accurate long-term electricity demand predictions are essential for the investment and operation of future energy systems (Grandon et al., 2024), this study employs regression methods to forecast Iran's electricity consumption and design demand side scenarios.

Table 1 summarizes previous system dynamics research results and highlights their differences compared to the current study.

Table 26. Comparison of past systems dynamics studies and current research

Row	Study	Country	Sector			Study focus
1	(Ford, 2001)	USA	*			Use of computer models for power plant simulation
2	(Nahavandi and Najafzadeh, 2012)	Iran	*		*	Comparison of two supply-side development approaches in demand management
3	(Qudrat-Ullah, 2013)	Canada	*		*	Investment in research and development (R&D)
4	(Pereira and Saraiva, 2013)	Spain	*			Long-term model for the generation expansion planning problem
5	(Mohaghar and Najafzadeh, 2017)	Iran	*			Long-term program development for electricity supply
6	(He et al., 2018)	China		*		Impact of Transmission and distribution tariff policies on electricity industry cash flow
7	(Sha et al., 2018)	China		*	*	Capital allocation strategy in the transmission and distribution sector
8	(Sha et al., 2018a)	China		*		Impact of transmission and distribution tariffs on capital investment allocation in the power grid
9	(Ahmadvand and Kalantari Hermzi, 2019)	Iran			*	Investment in distribution capacity development
10	(Monjazeb and Rezaei Movahed, 2019)	Iran		*		Transmission Losses
11	(Zambrano et al., 2019)	Colombia		*		Investment in transmission capacity, installed transmission capacity, current marginal cost, Transmission capacity marginal cost, desired transmission capacity marginal cost, electricity demand
12	(Saad et al., 2020)	Malaysia	*			Evaluation of tariff rate changes and their effects on production
13	(Dehghan et al., 2021)	Iran	*		*	Impact of energy price policies on supply and demand instability
14	(Dianat et al., 2021)	Iran	*			Systematic modeling of power generation development planning
15	(Li et al., 2022)	China			*	Electricity consumption forecasting using system dynamics tools

Row	Study	Country	Sector			Study focus
16	(Zahari and Mclelan, 2023)	Indonesia	*			Using a conceptual dynamic model to understand the electricity sector energy transition to renewables
17	(Loh and Bellam, 2024)	Singapore	*			Effect of government policies on hydrogen energy, low carbon electricity imports, and energy saving on energy security
Current study		Iran		*		Investigation of capacity development in power grid transmission to ensure sustainable electricity supply under different demand scenarios, considering variables such as losses, inflation, aging chain, and equipment depreciation.

Knowing that none of the mentioned researchers have specifically modeled the development of electricity transmission capacity based on different demand scenarios, this research, utilizing system dynamics tools, and focuses on predicting and simulating the construction of transmission capacity separately for 400, 230, 132, and 66-63 voltage levels based on expected demand scenarios under different conditions.

3. Research methodology

3.1. System dynamics

Figure 1 presents the steps of the system dynamics methodology (Sterman, 2002).

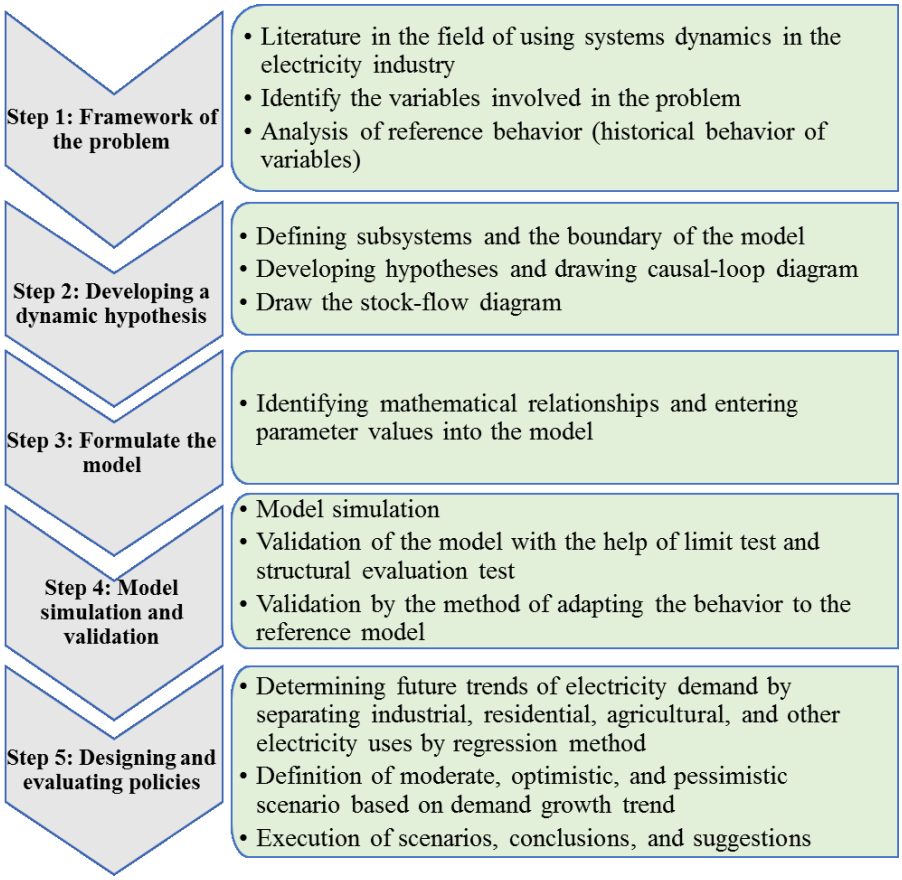

Figure 27. Research methodology (Sterman, 2002)

The explanation of Figure 1 is as follows:

Step 1- Problem Framework: This step is a meticulous process where the research problem is defined with precision. A thorough understanding of the problem is gained, and the approximate and deep structure of the research model is identified through a comprehensive study of existing sources and the valuable insights of stakeholders.

Step 2- Formulation of dynamic hypothesis: Dynamic hypotheses are extracted after identifying the subsystems, variables, and feedback loops present in each subsystem, and studying the behavior of variables in the past. In this stage, the causal loop diagram of the system is created using the identified variables and loops. The proposed causal loop diagram consists of three balancing loops and two reinforcing loops. Additionally, after identifying stock and flow variables, a stock and flow diagram is drawn.

Step 3- Formulating the Model: This step is a comprehensive process where the mathematical relationships between variables are determined, ensuring a deep understanding of the system's dynamics.Step 4- Simulation and Validation: In this step, the mathematical model is simulated using software designed for simulating systemic models. In this paper, Vensim PLE software has been used. In order to ensure that the model accurately represents the system's realities, validation is conducted. In order to validate the model, data from Iran's electricity industry from 1360 to 1400 were used, and the model was simulated using time steps of 0.015. Validation includes tests such as behavioral reproduction test, structural test, structural behavioral test, extreme condition test, and dimensional consistency.

Step 5- Designing and Evaluating Policies: In this step, to test strategies, the impact of these strategies is quantified using the model. In this article, scenarios were defined using regression analysis tools and based on Iran's electricity demand trend from 1350 to 1400. In the moderate scenario, it was assumed that the non-linear trend of Iran's electricity demand increase would continue similarly to before over a 20-year horizon. In the optimistic and pessimistic scenarios, it was assumed that electricity demand would be 10% lower and higher than the demand trend in the moderate scenario, respectively.

3.2. Choose of variables

The common voltage levels for power transmission capacity in the Iran power transmission system are 400 kV and 230 kV, and for sub-transmission, they are 132 kV and 63-66 kV. In this article, based on the classification presented in specialized reports, the aging chains of

transmission equipment have been categorized into equipment with a lifespan of less than 30 years, between 30 and 50 years, and over 50 years (Rajabi Mashhadi, 2018).

The key variables used in the modeling, along with their type, unit, and source, are presented in Table 2.

Table 27. Key Variables Defined in the Model

Row	Variable name	Type	Unit	Reference
1	Transmission capacity depreciation	Endogenous	$\frac{MVA}{Year}$	(Ahmad et al. 2016; He et al. 2018)
2	Transmission capacity development	Endogenous	$\frac{MVA}{Year}$	(Ahmad et al. 2016; Zambrano et al. 2019)
3	Transmission capacity with 30-50 years old	Endogenous	MVA	(Romero-Quete et al. 2016)
4	Transmission capacity with <30 years old	Endogenous	MVA	(Romero-Quete et al. 2016)
5	Transmission capacity with >50 years old	Endogenous	MVA	(Romero-Quete et al. 2016)
6	Transmission capacity	Endogenous	MVA	(Romero-Quete et al. 2016; Zambrano et al. 2019)
7	Transmission line development	Endogenous	$\frac{CK}{Year}$	Electrical industry experts
8	Transmission line	Endogenous	CK	Electrical industry experts
9	Cost of replacing	Endogenous	BRial	Electrical industry experts
10	Depreciated capacity replacing	Endogenous	$\frac{MVA}{Year}$	(He et al. 2018)
11	Investment in transmission capacity development	Endogenous	$\frac{BRial}{Year}$	(Zambrano et al. 2019)
12	Unit cost of transmission capacity development	Endogenous	$\frac{BRial}{MVA}$	Electrical industry experts
13	Desired transmission capacity	Endogenous	MVA	Electrical industry experts
14	Desired investment in transmission capacity development	Endogenous	$\frac{MVA}{Year}$	Electrical industry experts
15	Desired transmission losses	Endogenous	$\frac{1}{Year}$	(Pourkashani and Babaei 2003)
16	Desired vs current losses	Endogenous	$\frac{1}{Year}$	(Pourkashani and Babaei 2003)
17	Electricity demand	Exogenous	MW	(Dehghan et al. 2021)
18	Hazard function	Exogenous	DMNL	(Pe 2003)
19	Total capacity of the power plants	Endogenous	MW	(Dehghan et al. 2021)
20	Total transmission capacity	Endogenous	MVA	Electrical industry experts
21	Transmission losses	Endogenous	$\frac{1}{Year}$	(Pourkashani and Babaei 2003)
22	Unit cost of capacity development	Exogenous	$\frac{BRial}{MVA}$	Electrical industry experts

4. Dynamic hypothesis

The feedback loops considered in this research are three balancing loops and two reinforcing loops. The two balancing loops in the model are related to the lifespan of transmission equipment. Balancing loop B1 in Figure2 indicates the possibility of sudden burning due to increased transformer lifespan based on the Hazard distribution function (Pe, 2003).

Additionally, in balancing loop B2, transmission equipment is consumed due to increased lifespan and losses (He et al., 2018).

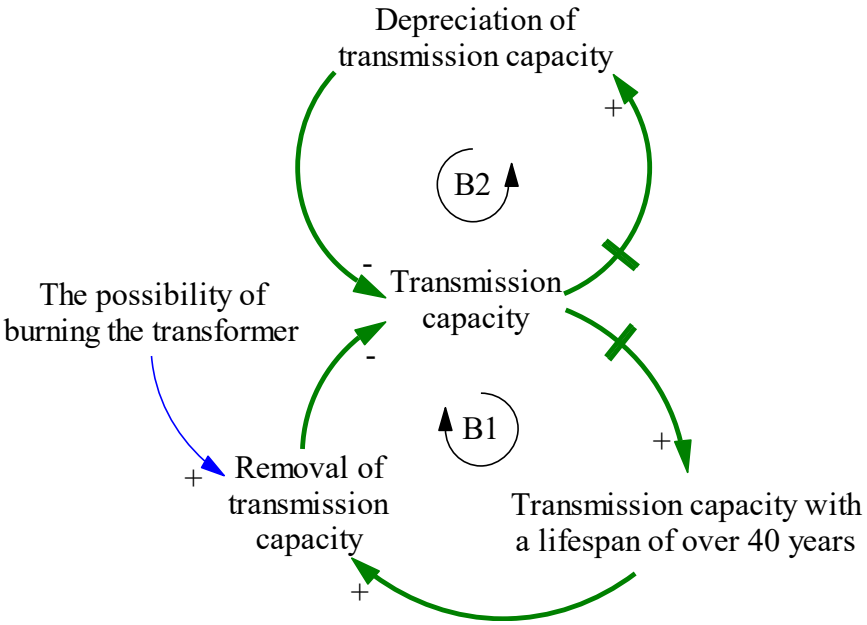

Figure 28. Two balancing loop impact on transmission capacity

The Hazard distribution function is based on Figure 3. In this diagram, as the lifespan of transformers increases, the probability of their burning with an S-shaped behavior increases.

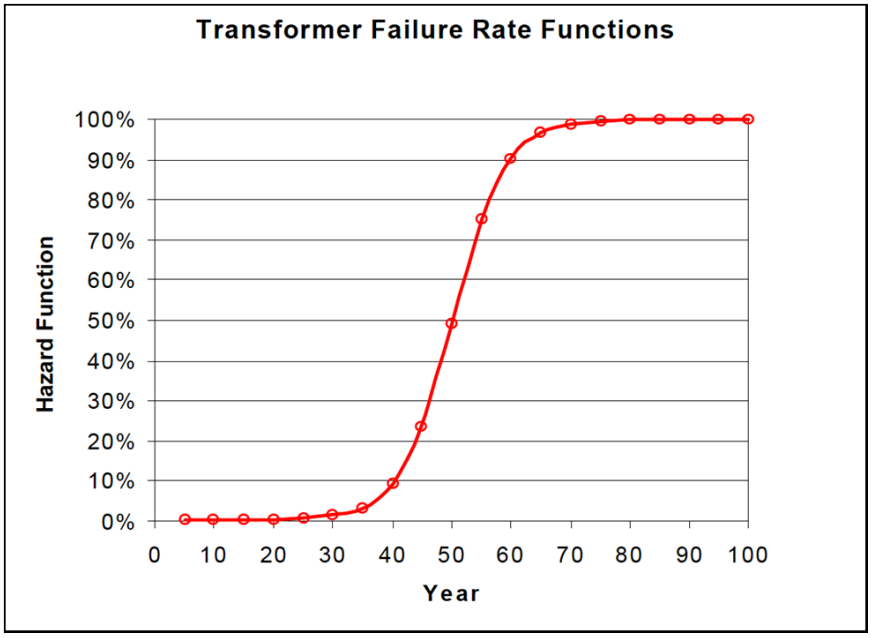

Figure 29. Hazard distribution function (PE, 2003)

In balancing loop B3 presented in Figure 4, with a decrease in transmission capacity, the difference between expected capacity and actual capacity increases, and investment also increases (Zambrano et al., 2019). With delayed investment, transmission capacity develops,

leading to increased capacity. Therefore, the decrease in transmission capacity will ultimately be compensated over time through this loop.

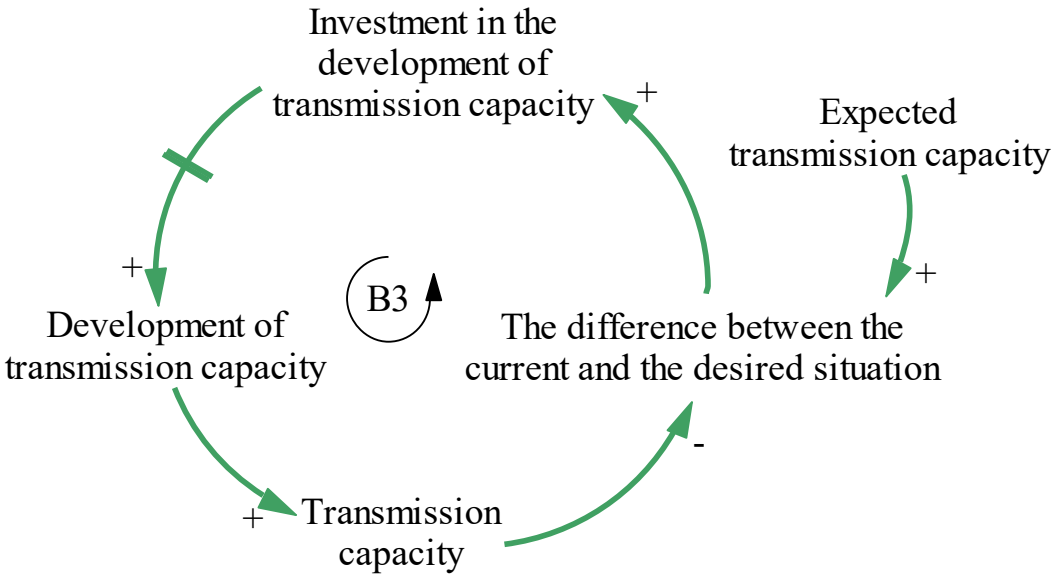

Figure 30. Third balancing loop impact on transmission capacity

The efficiency of the transmission network is defined as the ratio of network output power to its input power, and network losses are calculated by subtracting efficiency from 1. The reinforcing loop in Figure 5. illustrates the impact of transmission network losses on capacity development. This long-term influential loop shows that as investment in capacity development increases, capacity development expands and capacity increases. However, in the long term, the lifespan of the transmission network increases, and network losses also increase (Rajabi Mashhadi, 2018), necessitating more capacity to compensate for losses, ultimately leading to increased investment in capacity development. Given the qualitative essence of political factors in the system, such as the imposition of sanctions, inflation serves as a quantitative indicator of the influence of these factors on the development of the electricity transmission system. This exogenous variable elevates the unit costs associated with capacity expansion, subsequently impeding the pace of capacity development.

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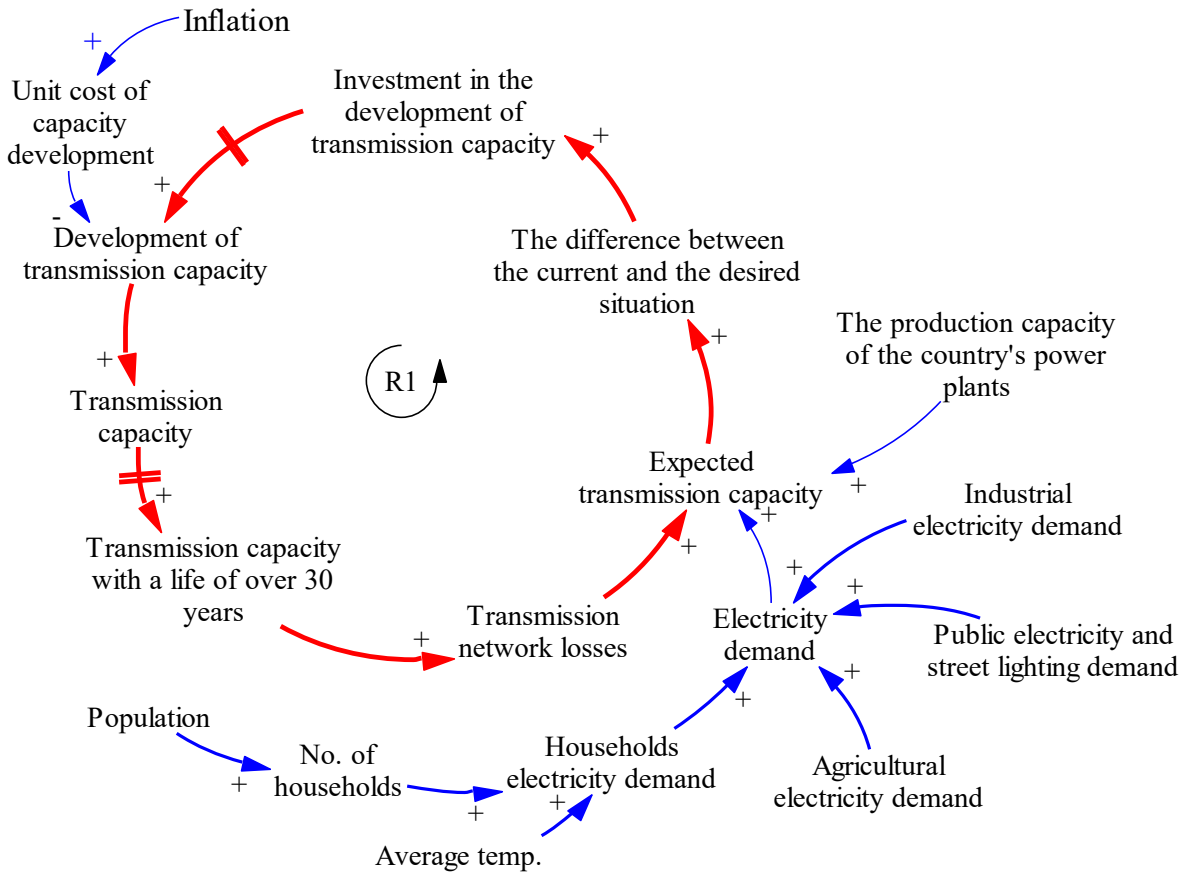

Figure 31. First Increasing Loop Impact on Transmission Capacity

In Figure 6, the country's electricity demand includes demand for household, agricultural, industrial, public, and street lighting electricity. In 1400, according to Figure 6, the industrial, household, and agricultural sectors accounted for 39%, 35%, and 15% of electricity consumption, respectively, and are among the major electricity consumers. The scenarios defined in the model are based on the relationships presented regarding electricity demand.

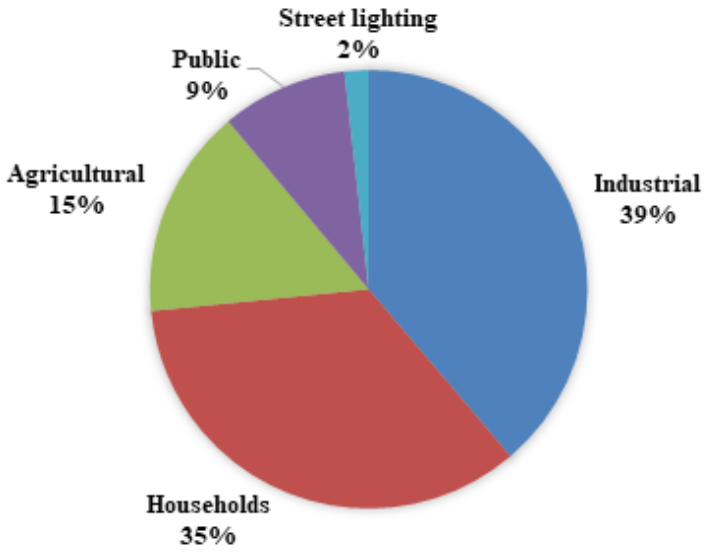

Figure 32. Share of electricity consumption users in 1400 (Tavanir, 2022)

Figure 7 shows the amount of power in the transmission network that has a lifespan of over 30 years. As evident, from 1376 onwards, the lifespan of the power transmission network has reached 30 years, leading to an increase in losses caused by this equipment.

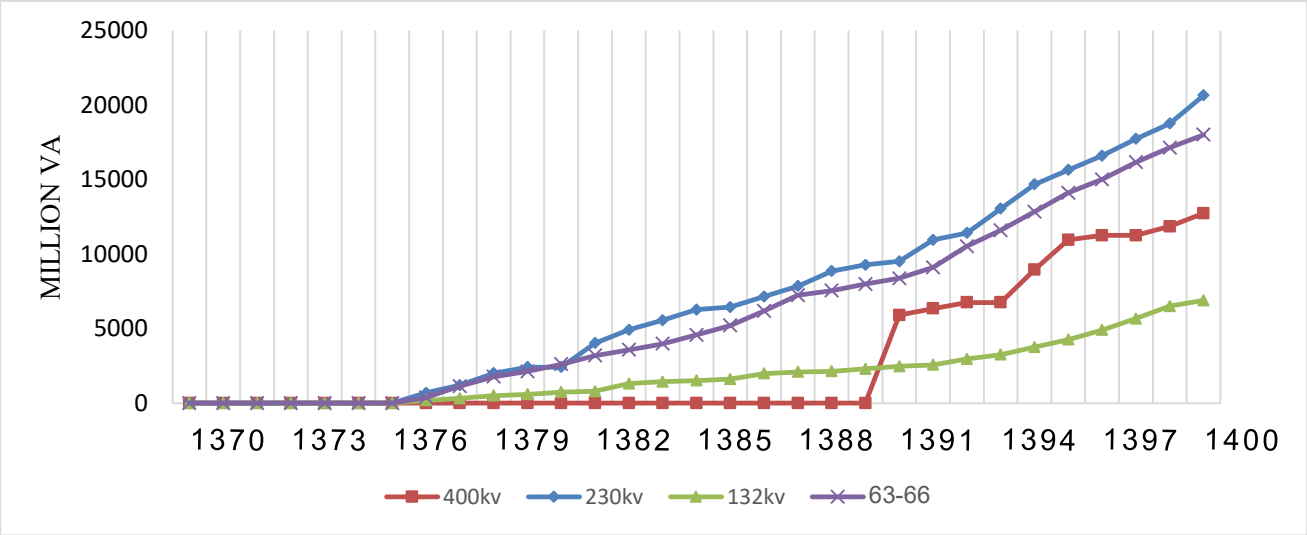

Figure 33. Transmission network power capacity over 30 years separated by transformer type (Tavanir, 2022)

Figure 8 also illustrates the second reinforcing loop, showing the impact of network losses and expected losses on strategies in capacity development. As the developed capacity increases, the lifespan of these equipment increases in the long term, leading to an increase in their losses (Rajabi Mashhadi, 2018; Romero-Quete et al., 2016). The difference between actual losses and targeted losses in strategies increases the decision to renovate and invest in new capacity development, resulting in increased transmission capacity.

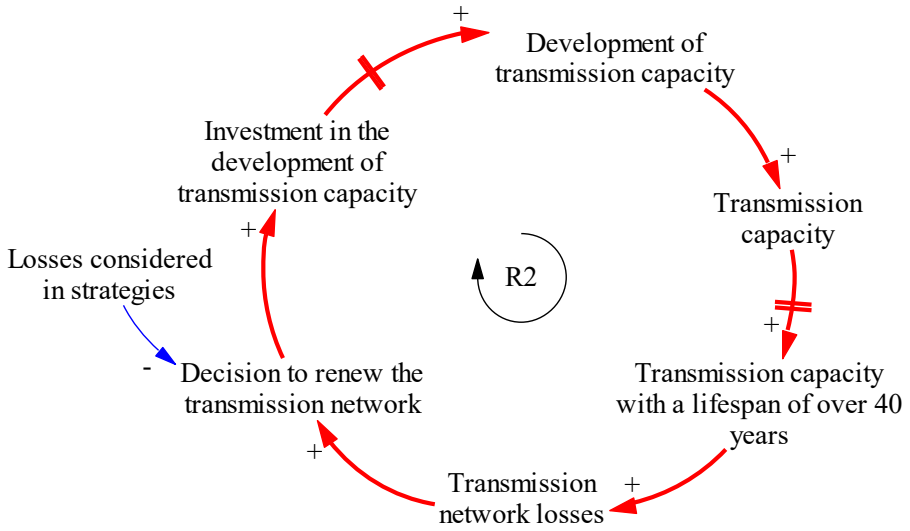

Figure 34. Second reinforcing loop impact on transmission capacity

By joining all the loops explained above, Figure 9 creates an overall causal loop diagram of the research.

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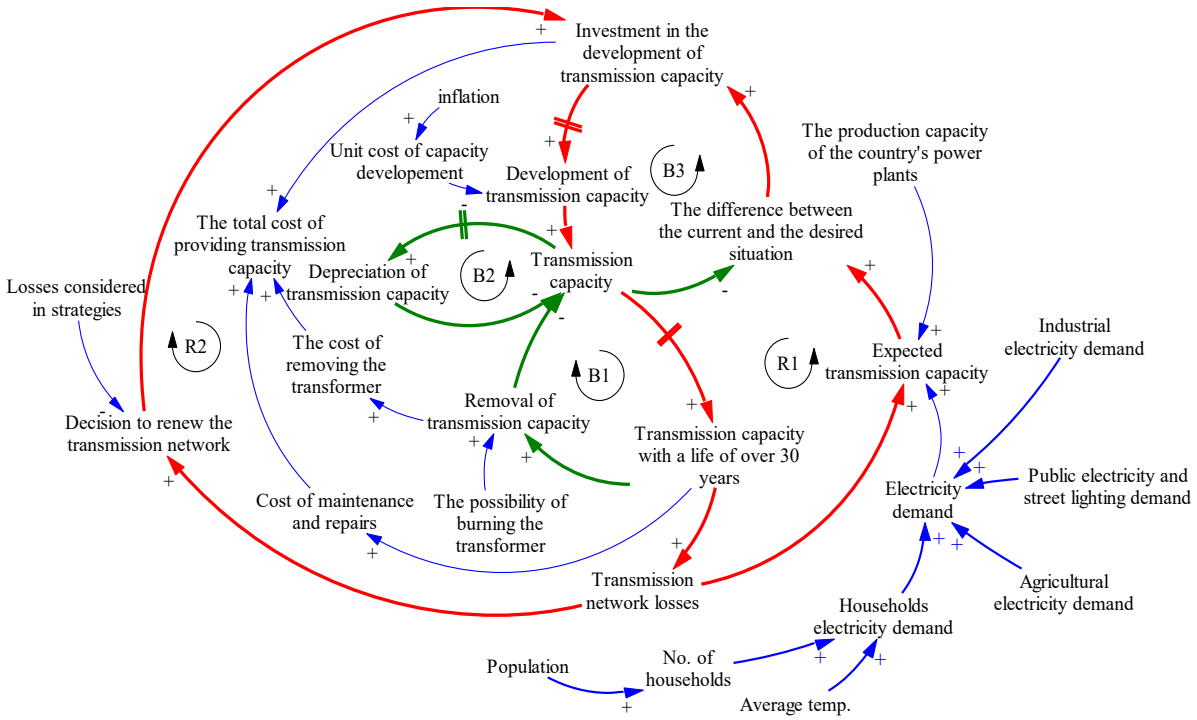

Figure 35. Overall Causal loop diagram of the Research

5. Stock and flow diagram

Considering variables such as transformer capacity, transmission line length, and Consumer Price Index (CPI) as stock variables, the stock and flow diagram presented in Figure 10 and Figure 11 has been developed. After drawing the stock and flow diagram, it is necessary to define the mathematical relationships between variables. The mathematical relationship between the amount of post-capacity development based on first-order information delay is considered. Equation 1 shows the relationship between the amount of investment and the amount of developed capacity. In this equation, D_K represents the amount of development for each capacity, I_K is the amount of investment made in each capacity, and U_K represents the unit cost of developing each capacity. In equation 1, Delay1i function represents first-order information delay.

$$D_K = Delay1i\left(\frac{I_K}{U_K}, 1, 0\right) \tag{1}$$

$$K \epsilon\ 400KV, 230KV, 132KV\ and\ 63-66KV\ transmission\ capacity$$

It is worth mentioning that the amount of investment in the field of transmission capacity expansion is also calculated based on the expected transmission capacity (DTC) and expected losses (DTL). In Equation 2, TC represents the current amount of transmission capacity, and TL represents the current amount of losses.

$$I_K = U_K \times max(0, DTC - TC) \times (1 + DTL - TL) \quad (2)$$

The parameter determining the amount of transmission losses is the average age of all transmission capacity, calculated by Equation 3. In this equation, TC_i represents the amount of transmission capacity with an age of i years, and A represents the average age of the transmission network.

$$A = \frac{\sum_i i \times TC_i}{\sum_i i} = \frac{1 \times TC_1 + 2 \times TC_2 + \cdots + TC_{100}}{1 + 2 + 3 + \cdots + 100} \quad (3)$$

To calculate the amount of transmission network losses, a Lookup table function has been used. According to Equation 4, the amount of network losses is a function of the average age of the transmission network (A), and for each value of A, the network losses are calculated using interpolation.

$$Tl = F\ (A) \quad (4)$$

For better presentation, the aging chain section of transmission capacities designed separately for the four mentioned capacities is presented in the stock and flow diagram. Figure 10 shows variables affecting transmission capacity. In this diagram, the amount of investment in capacity development and unit cost of capacity development enter the aging chain section, and the amount of transmission capacity is separated by four capacities exiting from this section. The model related to transmission capacities is also shown in Figure 11.

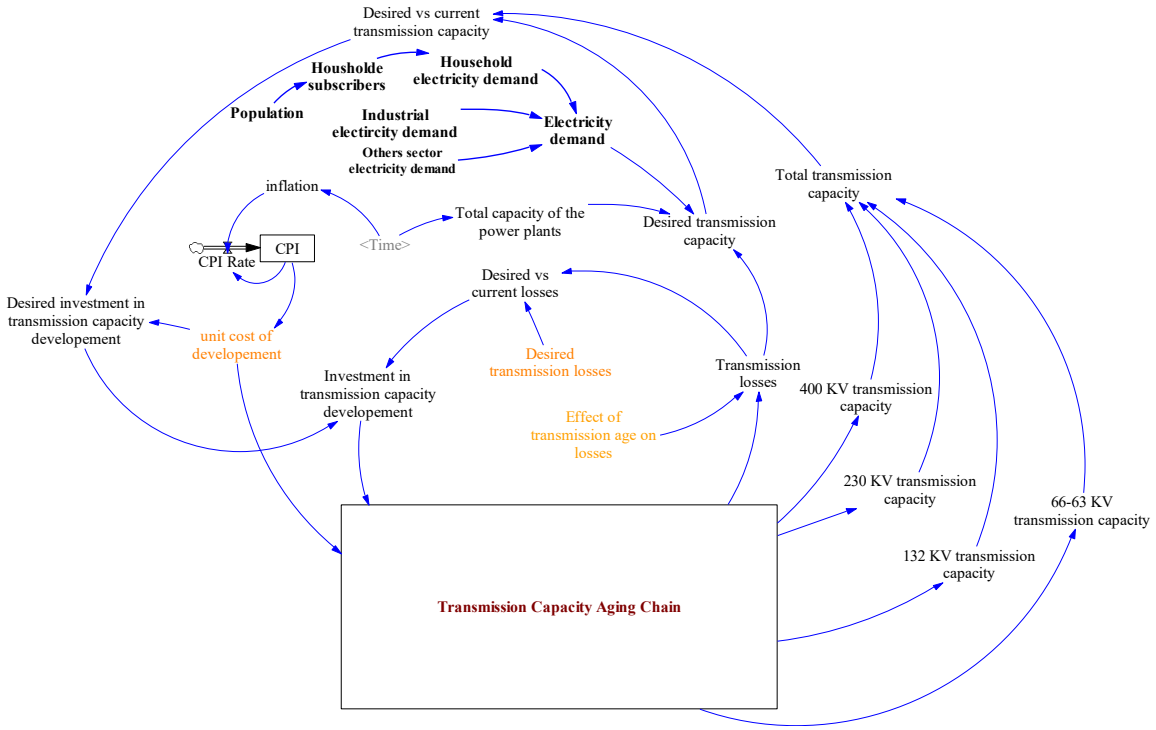

Figure 36. Stock and flow diagram containing variables affecting transmission capacity

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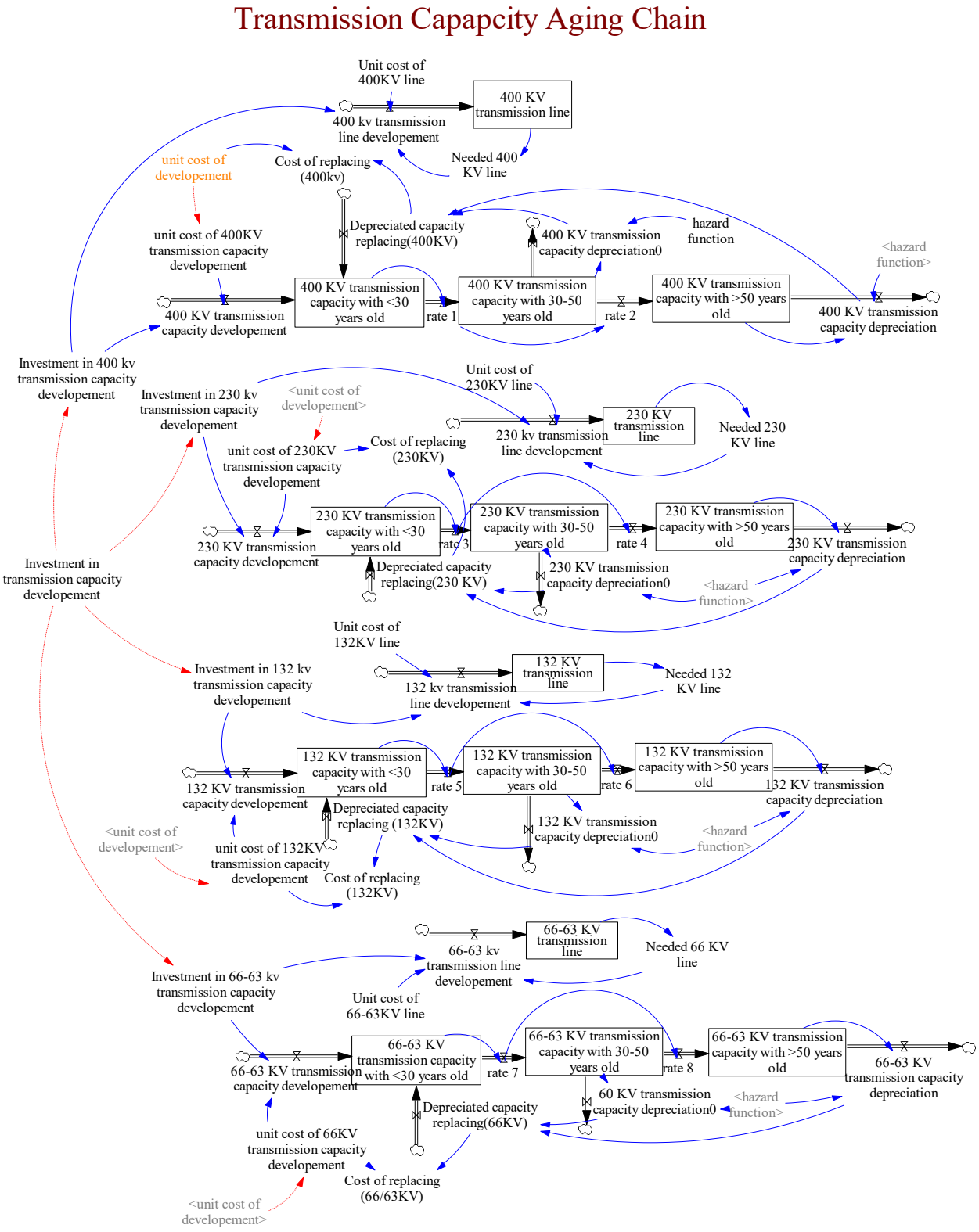

Figure 37. Stock and flow diagram of aging chain part in transmission capacity

6. Model validation

In this section, after simulating the model, its validation has been carried out. In this research, model validation has been confirmed using various methods such as structural evaluation, extreme condition testing, dimensional consistency, and behavioral reproduction tests (Sterman, 2002).

Here, only the presentation of results from dimensional consistency and behavioral reproduction testing are provided. Figure 12 displays the compatibility results of the model dimensions, which were performed using the Vensim software.

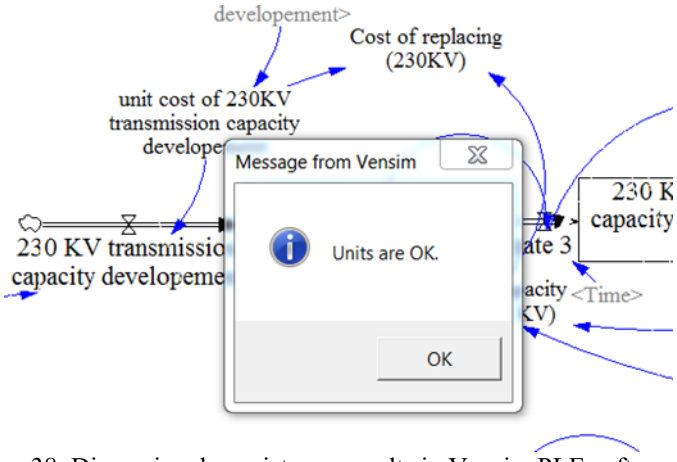

Figure 38. Dimensional consistency results in Vensim PLE software

In behavioral reproduction testing, the simulation results of the model are compared with available historical data for key variables. The current research model was able to accurately simulate the behavior of transmission capacity variables. Figure 13 shows the results of the simulation and historical data for the 400 KV transmission capacity variable. As observed, the model was able to reconstruct the behavior of this variable with an accuracy exceeding 90%. Also, Figure 14, Figure 15, and Figure 16 show the results of the behavioral reproduction test for 230, 132, and 63-66 kilovolt transmission capacity, respectively.

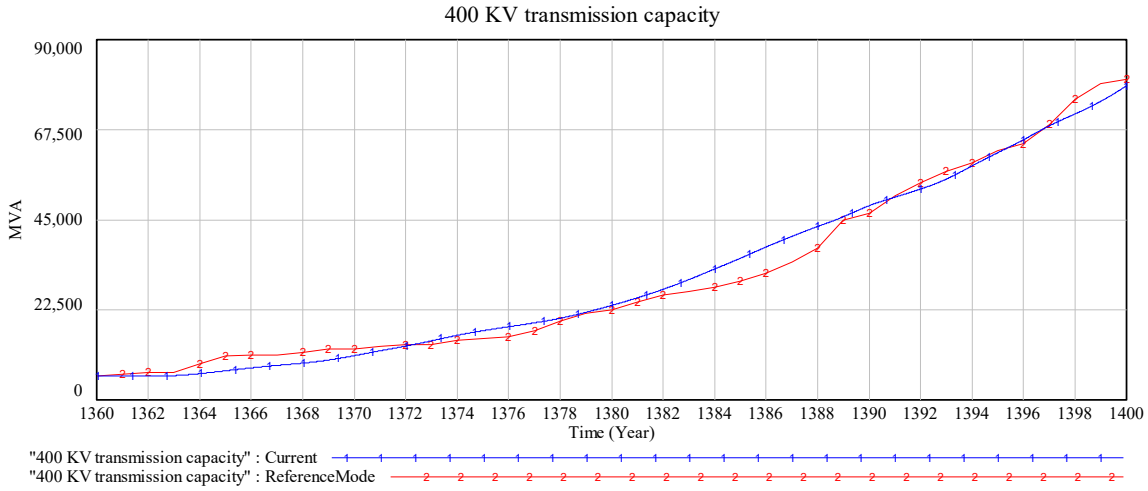

Figure 39. Comparison of historical data and simulation result of 400 KV transmission capacity (MAE: 6.9%)

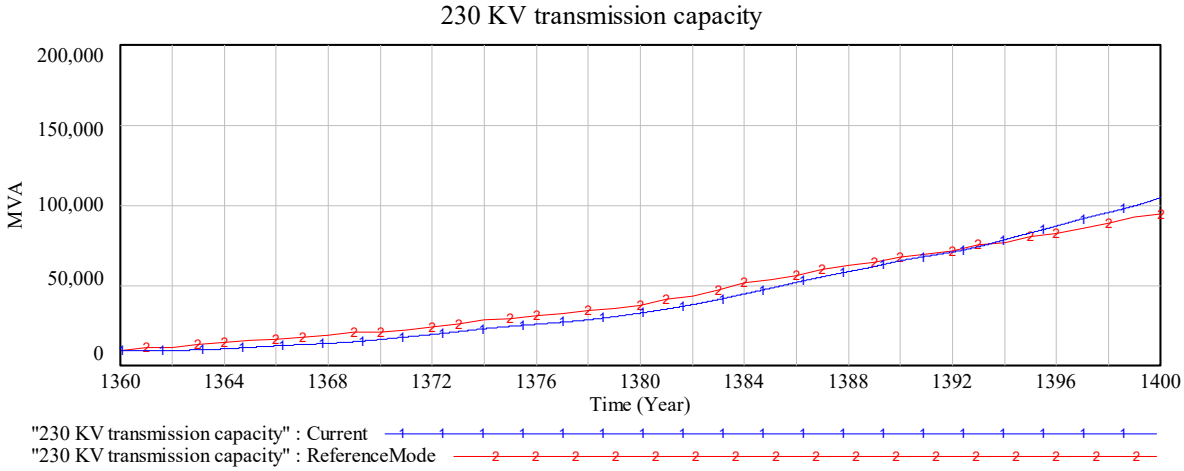

Figure 40. Comparison of historical data and simulation result of 230 KV transmission capacity (MAE: 9.9%)

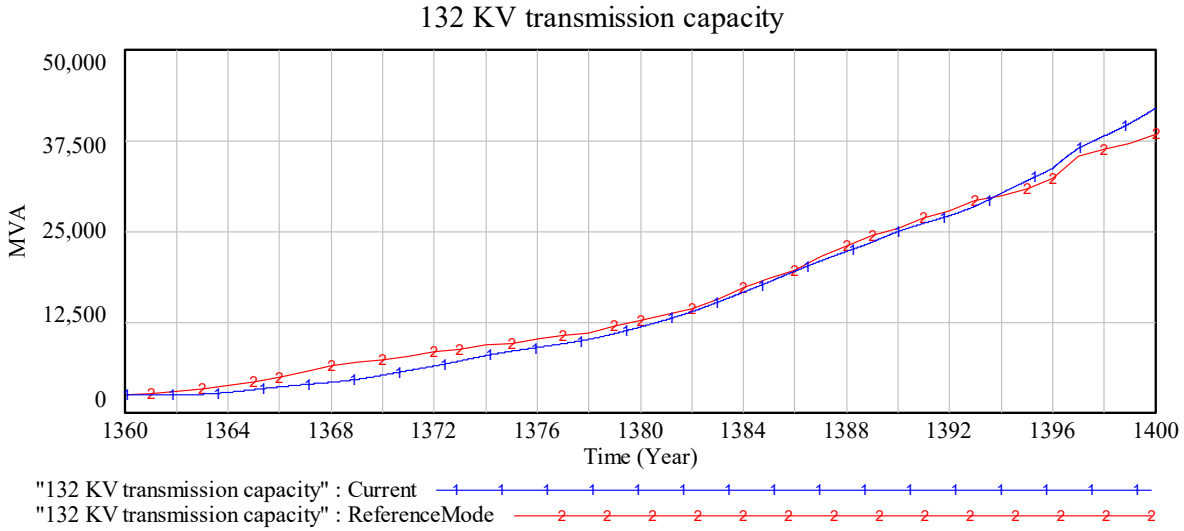

Figure 41. Comparison of historical data and simulation result of 132 KV transmission capacity (MAE: 6.9%)

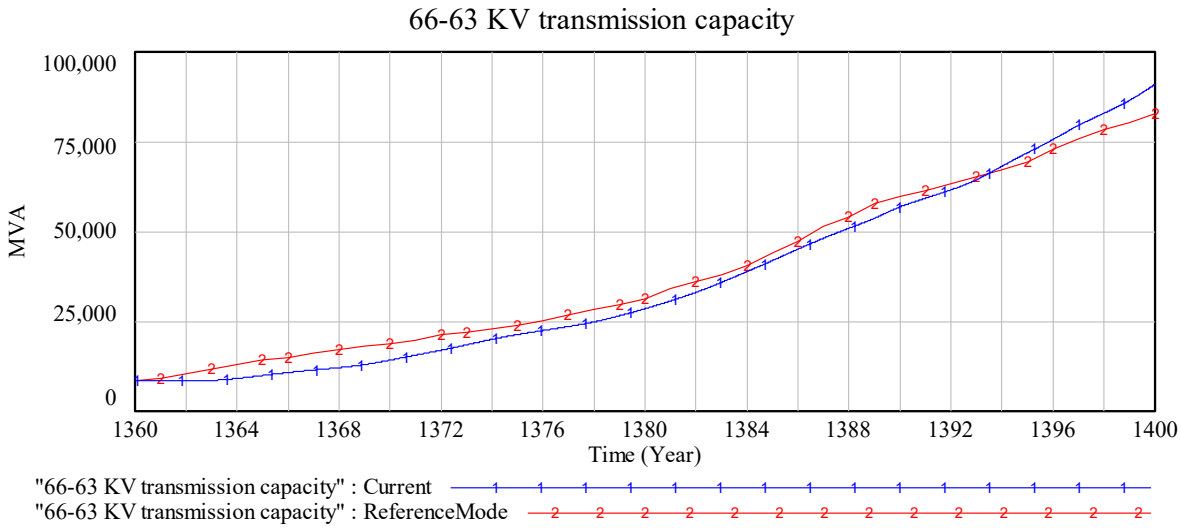

Figure 42. Comparison of historical data and simulation result of 63-66 KV transmission capacity (MAE: 8.4%)

7. Future analysis of the electricity transmission industry

In this section, the expected trend has been predicted based on the major electricity consumers identified in Figure 6 to investigate the impact of electricity demand on the level of transmission capacity development. Regarding the industrial sector, the consumption trend over time is shown in Figure 17.

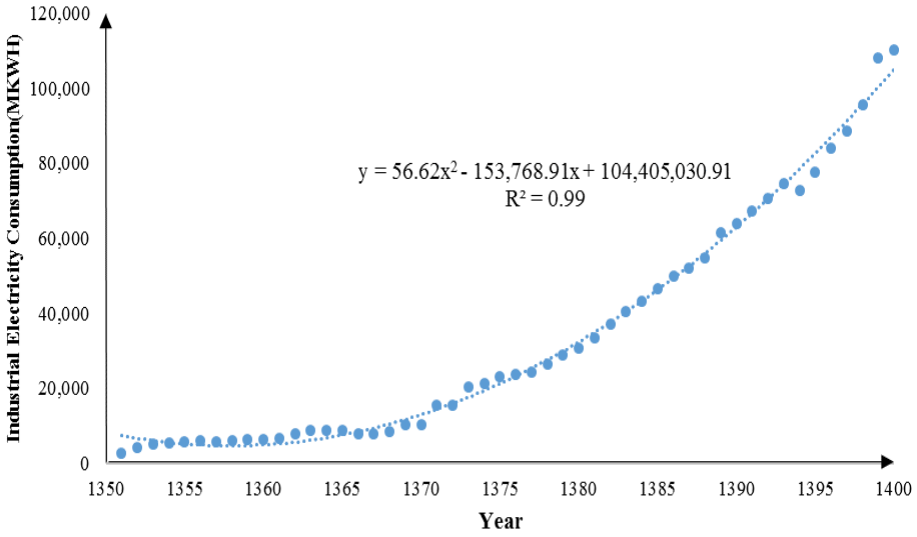

Figure 43. Industrial electricity consumption trend in Iran

Equation 5 shows the best relationship that can predict electricity consumption in the industrial sector based on the Persian year as follows.

$$ID = 56.45 \times Y^2 - 153312 \times Y + 104091642 \quad (5)$$

In the residential sector, Figure 18 shows the number of household subscribers based on the population from 1346 to 1400. The relationship between the increase in the number of household subscribers and the country's population is not linear, and the slope of its increase has gradually increased over time. The reason for this is the decrease in household size at the national level. Equation 6 shows the best function that can represent the relationship between the number of household subscribers (HS) based on the population (P).

$$\mathrm{HS} = 0.0076 \times P^2 - 0.3887 \times P + 6.4377 \quad (6)$$

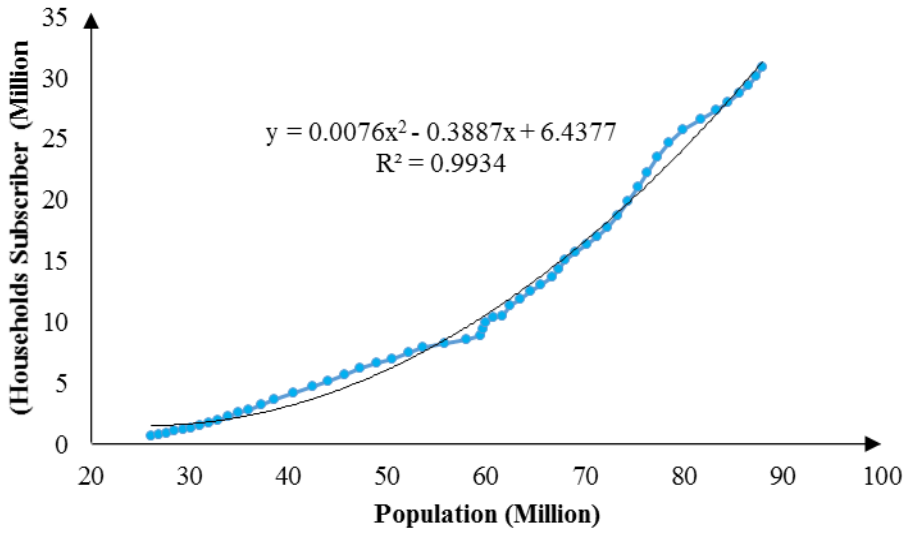

Figure 44. Household subscriber numbers based on population

In order to examine the relationship between household electricity demand and the number of subscribers in this sector, the correlation between demand and the product of subscribers and average air temperature was investigated (Figure 19). The best relationship that can represent the relationship between electricity demand and the product of subscribers and air temperature is a nonlinear relationship presented in Equation 7.

$$\mathrm{H}D = 157.13 \times T \times HS - 5346.5 \quad (7)$$

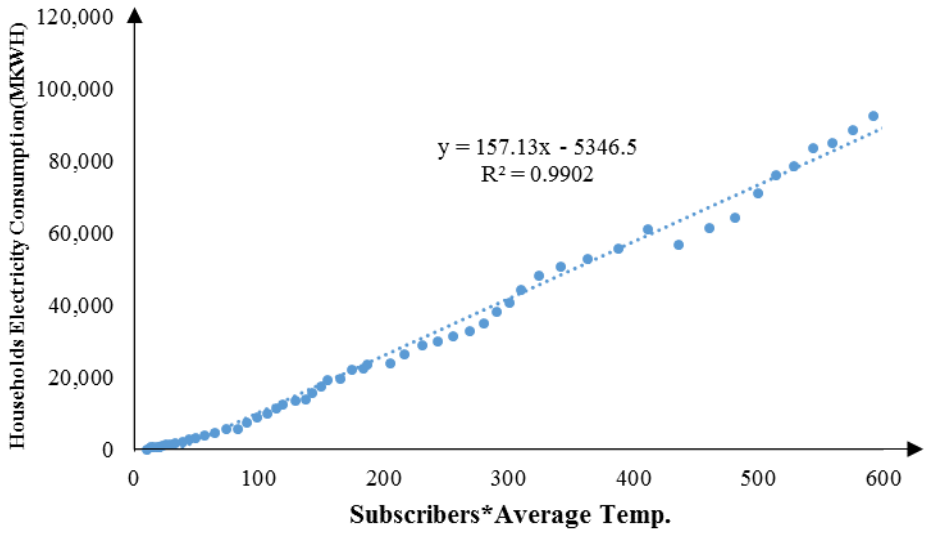

Figure 45. Household electricity demand based on the number of subscribers and average temperature

Figure 20 shows the agricultural electricity consumption trend over time. Equation 8 presents the best relationship for modeling electricity consumption (AD) over time in the agricultural sector.

$$AD = 29.97 \times (Y)^2 - 81587.15 \times (Y) + 55522451.95 \quad (8)$$

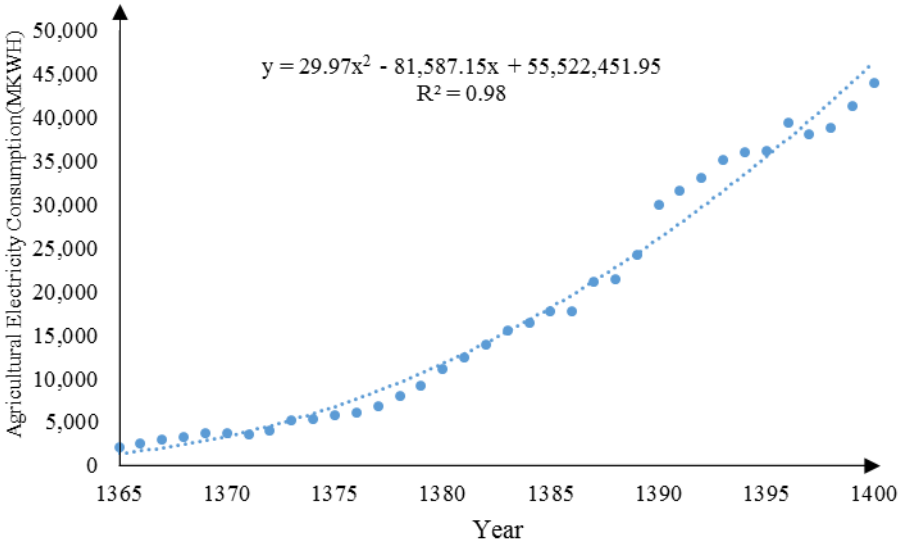

Figure 46. Agricultural electricity consumption trend over time

Other electricity demands (OD) in the country are related to public and street lighting consumption. The relationship of increasing demand in this sector is also in accordance with the equation presented in Figure 21, which increases linearly over time (Equation 9).

$$OD = 2136.99 \times (Y) - 2937529.95 \quad (9)$$

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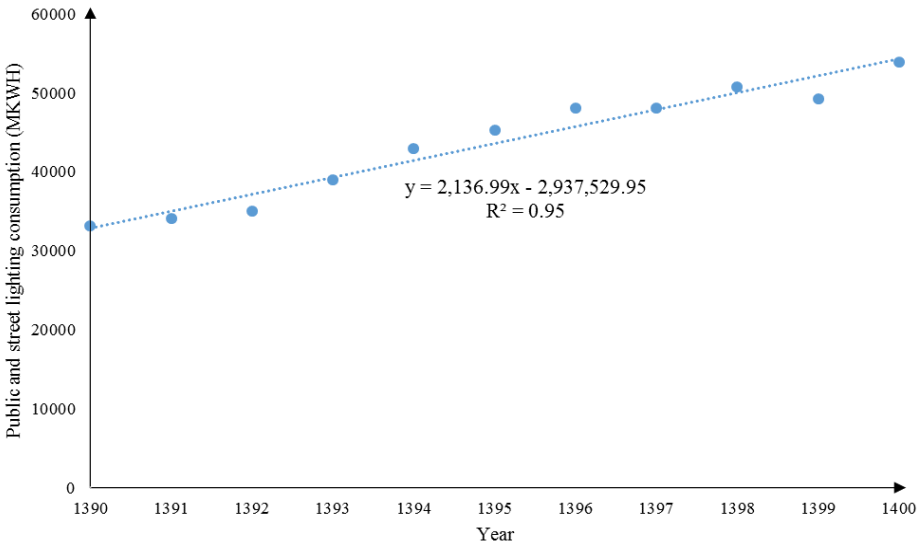

Figure 47. Public electricity consumption and street lighting trend

7.2. Scenario 1: Continuation of electricity demand trend until 1420 (moderate scenario)

In scenario one, it is assumed that the country's electricity demand, which is formulated based on the causal relationships in Figure 22, will increase according to equations 5 to 9. This increase occurs under conditions where the air temperature remains at the same level as the average temperature of 1400, which is 19 degrees Celsius, and the country's population increases linearly to reach 108 million by 1420.

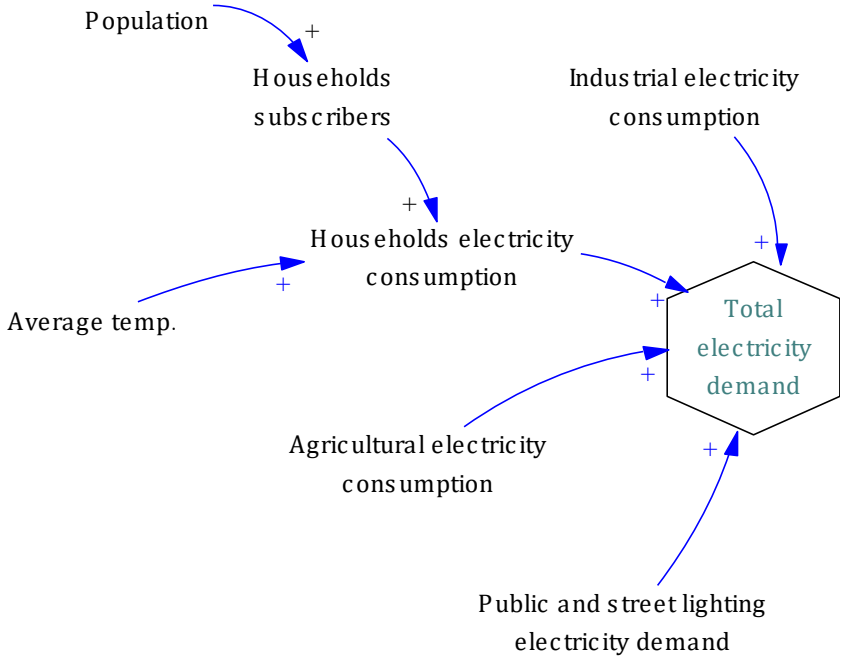

Figure 48. Causal relationships indicating the country's electricity demand

Under these conditions, the behavior of Iran's total electricity demand will be as shown in Figure 23.

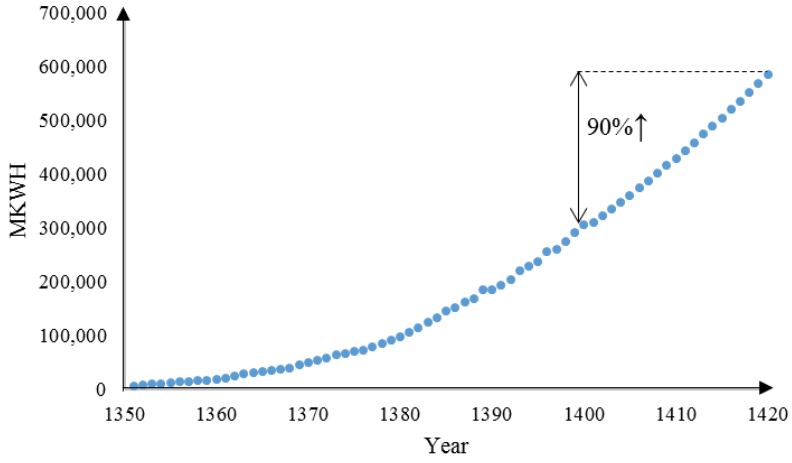

Figure 49. The trend of Iran's electricity demand until 1420 in scenario 1

In this scenario, which is considered the most likely scenario, the prediction provided regarding the country's electricity demand has been integrated into the model. According to Figure 24, the amount of transmission capacity increases to compensate for demand.

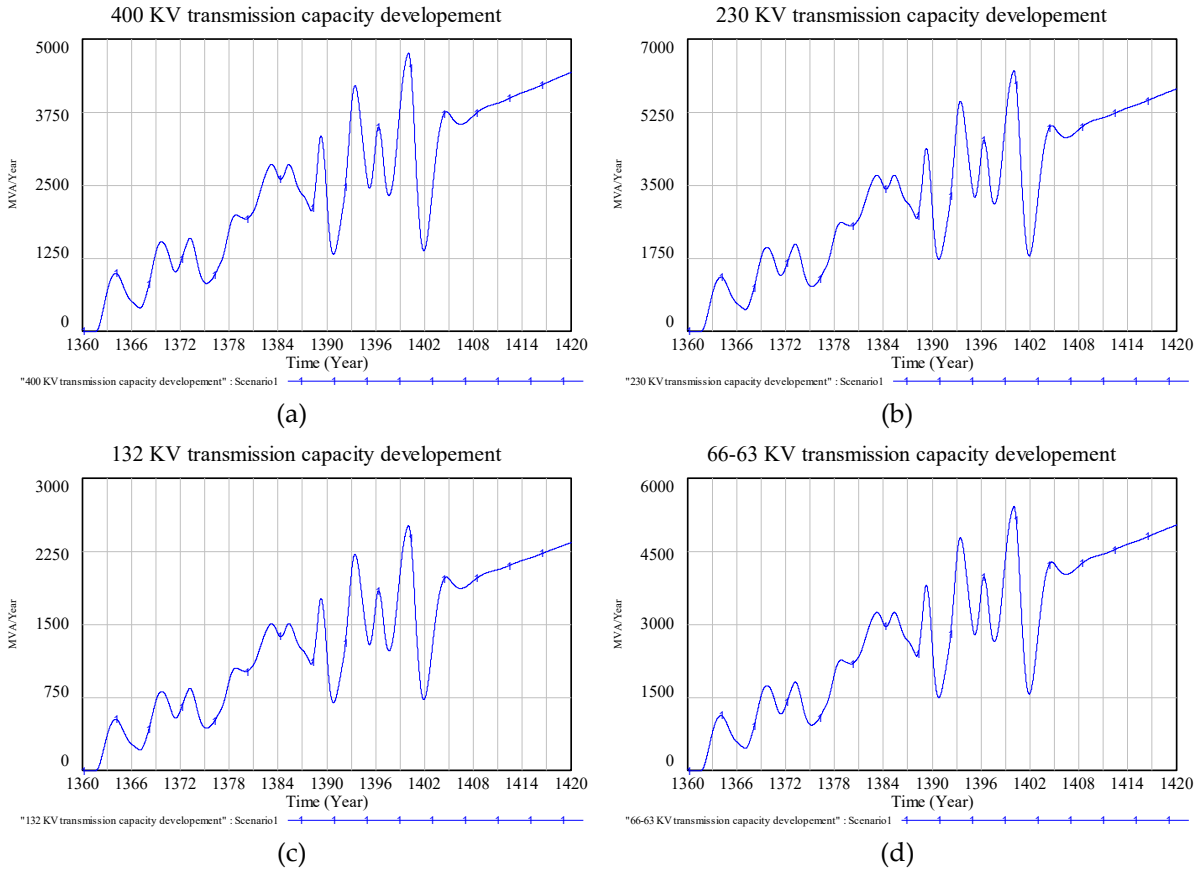

Figure 50. Transmission capacity behavior by scenario 1: (a) 400 KV; (b) 230 KV; (c) 132 KV; (d) 63-66 KV

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The outcomes of simulating the scenario of maintaining the existing conditions (moderate scenario), as the numerical results depicted in Table 3, indicate that an expansion of 89%, 112%, 115%, and 110% in the transmission capacities of 400, 230, 132, and 63-66 KV in the 20-year horizon is required to meet the current electricity demand within the network.

7.3. Scenario 2: Increases in electricity demand until 1420 (pessimistic scenario)

In this scenario, the country's electricity demand is assumed always to be 10% higher than the prediction provided in scenario 1 (Figure 25).

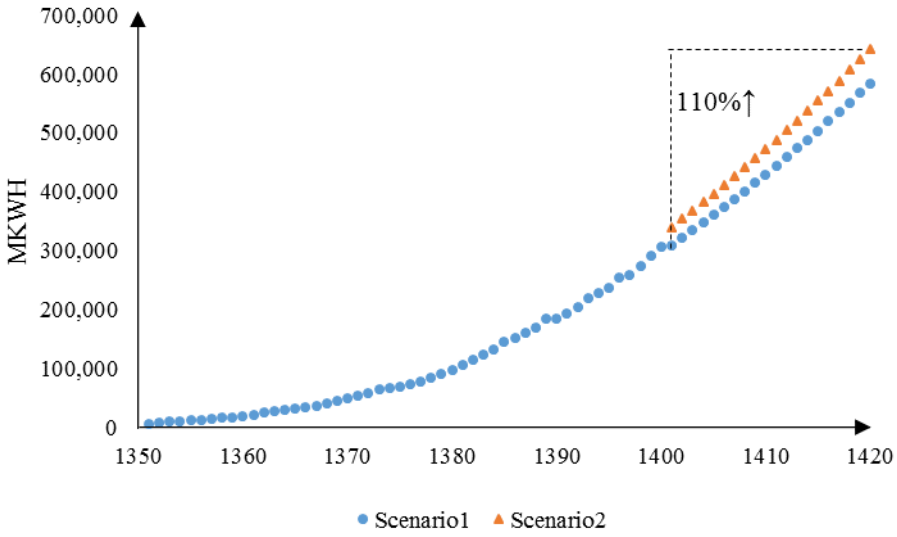
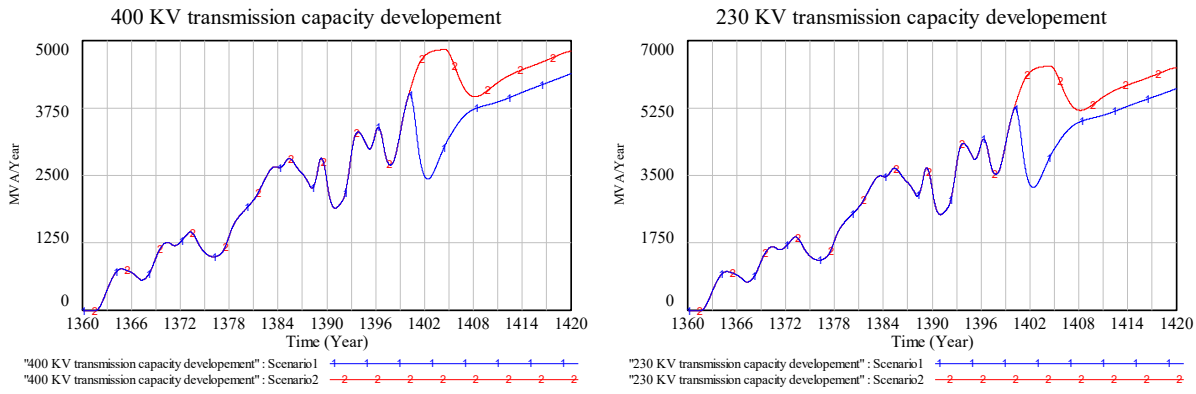
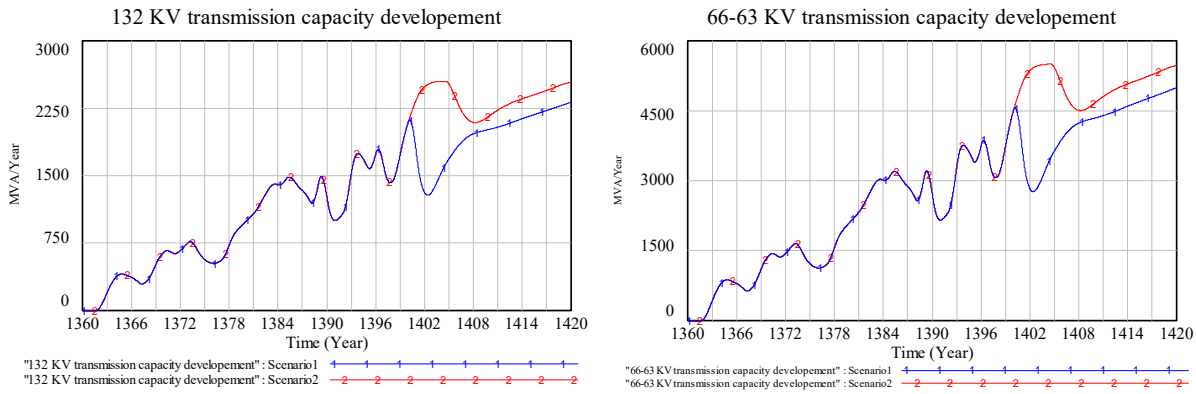


Figure 51. Prediction of country's electricity consumption based on a pessimistic trend

By implementing this scenario, the results shown in Figure 26 are achieved. These findings suggest that if electricity demand follows a trend with a steeper slope than the current conditions, there will be a substantial requirement for enhanced transmission capacity. In this scenario, the improvement policy is described as 400, 230, 132, and 63-66 KV transmission capacity need to increase by 108%, 133%, 136%, and 131%, respectively, as well as an overall increase in transmission capacity by 126% to 1420 compared to 1400.



(a) (b)



(c) (d)

Figure 52. Transmission capacity behavior by the two scenarios: (a) 400 KV; (b) 230 KV; (c) 132KV; (d) 63-66 KV

7.4. Scenario 3: Decrease in electricity demand trend (optimistic scenario)

Contrary to previous scenarios, in scenario 3, electricity demand is assumed to decrease by 10% each year from 1401 onwards. In this scenario, electricity demand follows a quadratic trend, as shown in Figure 27.

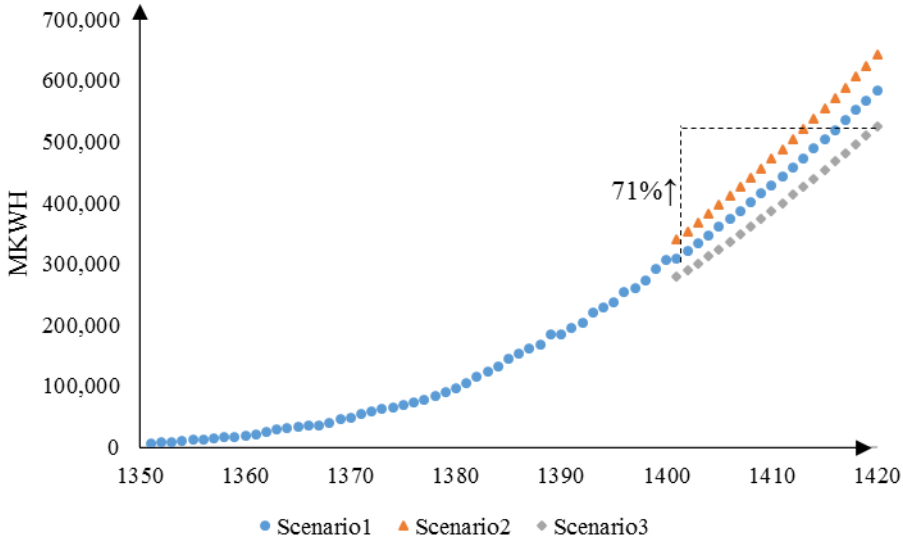


Figure 53. The country's electricity consumption prediction based on an optimistic trend

Under these conditions, the following results regarding model variables are obtained. The results show that if demand decreases by only 10% each year compared to scenario 1, the construction of transmission capacity until 1408 may decrease, and after that, construction should start to increase according to the trend presented in Figure 28.

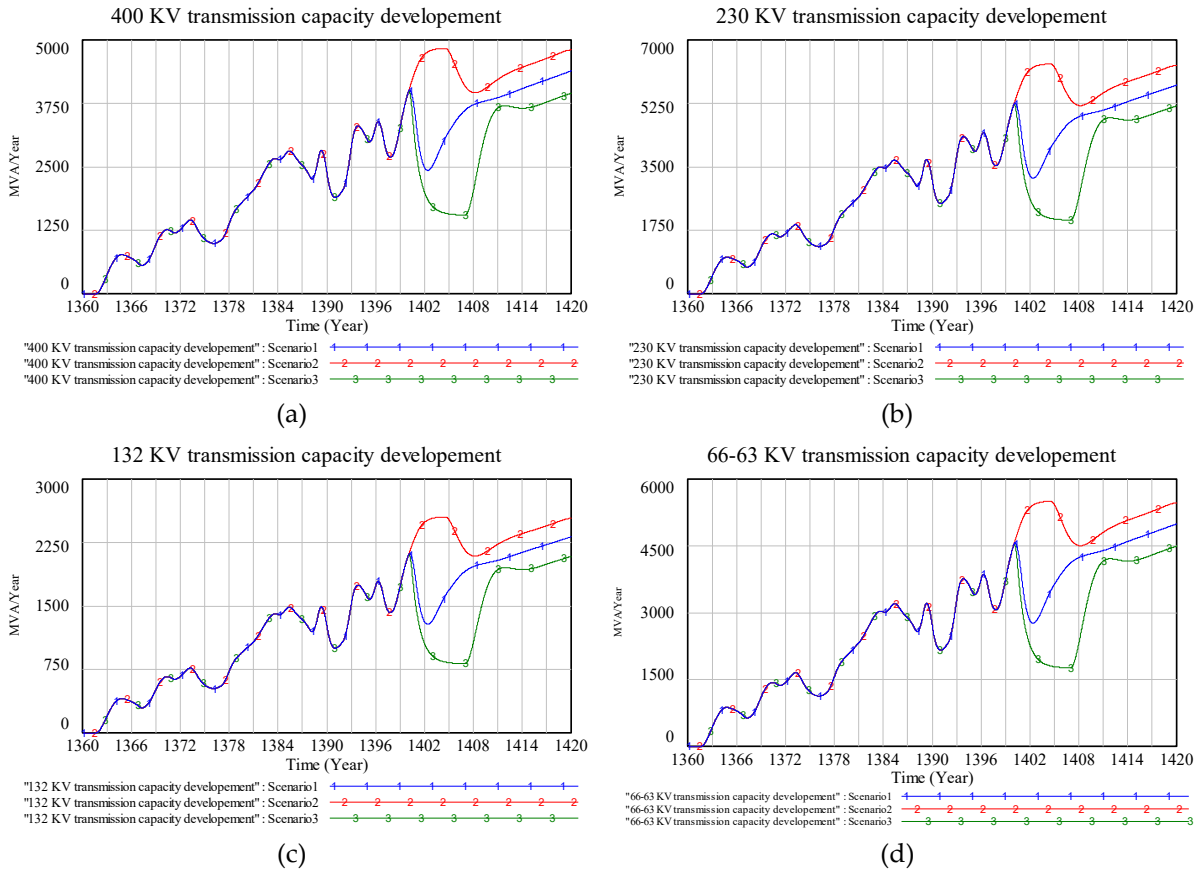


Figure 54. Transmission capacity behavior by the three scenarios: (a) 400 KV; (b) 230 KV; (c) 132KV; (d) 63-66 KV

Finally, the outcomes of simulating the scenario of optimistic scenario, as depicted in Table 3, indicate that an expansion of 85%, 70%, 91%, and 94% in the transmission capacities of 400, 230, 132, and 63-66 KV is required to meet the low incremental slope of the electricity demand within the network.

Table 28. Results of implementing 3 research scenarios

Variable	1400	Moderate scenario (In 1420)		Pessimistic scenario (In 1420)		Optimistic scenario (In 1420)	
		Value	Change*	Value	Change	Value	Change
Total transmission capacity	295,642	607,793	106%	668,512	126%	547,020	85%
400 KV	80,203	151,322	89%	166,591	108%	136,039	70%
230 KV	94,318	200,137	112%	220,152	133%	180,103	91%
132 KV	38,360	82,504	115%	90,566	136%	74,435	94%
63-66 KV	82,761	173,829	110%	191,202	131%	156,441	89%
The difference between the required and the created capacity	24,125	23,007	-5%	25,000	4%	20,700	-14%

* The unit of variables is MVA and in the scenarios, the percentage of change compared to the year 1400 has been calculated.

8. Conclusion

Due to the abundance of influential variables in the electricity transmission industry, short-term and long-term planning regarding the amount, timing, and location of construction has always faced multiple challenges. This research, while reviewing previous domestic and foreign studies, provides a suitable framework for analyzing policies related to investment in the transmission industry. The subsystem diagram of this research considers inflation, demand, and electricity supply variables. In the causal loop diagram, important variables such as available transmission capacity, equipment depreciation, equipment age, and the probability of transformer burning are considered, and direct and indirect relationships between them are modeled. Subsequently, a stock and flow diagram is drawn, and after entering the mathematical relationships between the variables, simulation and validation of the model are performed. The results of reconstructing the historical behavior indicate a high accuracy of over 90% in simulating the behavior of transmission capacities over the past 40 years. After validating the model, three scenarios are simulated based on the growing demand trend. To define scenarios, initially, the trend of electricity demand in the country was determined by separating industrial, residential, agricultural, and other electricity uses. In the first scenario, it was assumed that the demand trend would increase as in the past. In these conditions, the country's electricity demand is projected to increase by 90% by the year 1420 compared to 1400. This finding, which is the result of the current research statistics, should be taken into consideration by the experts and decision-makers in the electricity industry. In the second scenario, it was assumed that electricity demand would be 10% higher each year compared to the predicted trend in the first scenario. In the third scenario, it was assumed to be 10% lower.

The results show that if the total transmission capacity by 1420 increases by less than 85%, the country will face a shortage of transmission capacity. Furthermore, if the total transmission capacity increases by 126%, it will fully cover electricity consumption demand, even if the demand growth rate is 10% higher than continuing the trend. However, if we want to cover the current growth trend in electricity demand in the country until 1420, the total transmission capacity must increase by 106%.

It is worth noting that the system dynamics approach is a powerful tool for analyzing complex systems and understanding their behavior over time. However, it has limitations when it comes to managing unforeseen disruptions, such as technological changes or significant policy shifts. As a result, the numerical results obtained are based on the assumption that sudden shocks do not impact the country's electricity distribution system.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Improving the System of Urban Development Plan by Formulating the Mess and Using Soft Systems Methodology

Marzieh Samadi-Foroushani[a,b], Amir Shahrabi Farahani[c,d] , Soheil Kousari[e,d] , Mohammad-Javad Keyhanpour[f] , Ali Nasiri[g,b *]

[a] *Department of Industrial Engineering, Eyvanekey University, Eyvanekey,Iran.*
[b] *Tehran Disaster Mitigation and Management Organization, Tehran, Iran.*
[c] *Islamic Azad University, Central Tehran Branch, Tehran, Iran.*
[d] *Program and Budget of Tehran Municipality, Tehran, Iran.*
[e] *Department of Environmental Engineering, University of Science and Research, Tehran, Iran.*
[f] *Department of Civil Engineering, Islamic Azad University, Tehran, Iran.*
[g*] *Faculty of Health and Health Management Research Center, Baghiyatallah University of edical Sciences, Tehran, Iran.*

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ABSTRACT

The urban development planning process in Tehran municipality has been implemented for about two decades in the form of compiling four medium-term urban development plans of Tehran. Despite the efforts made, there are challenges to achieving the goals. This research has analyzed the barriers and identified solutions to improve the system of the development plan of Tehran by formulating the mess and using soft systems methodology during a systemic intervention by planning the learning process in practice. The innovative research method is the embedding of mess formulation in soft systems methodology. Formulating the mess analyses the barriers to identifying inefficiencies about aspects of how power, wealth, knowledge, value, and aesthetics are produced and distributed in a social system. Soft systems methodology is an action-research approach for learning human systems in complex problem situations. After a thematic review by referring to the key actors involved in formulating Tehran's urban development plan, first, the problem situation was analyzed, and a rich picture of the problem was drawn. According to formulating the mess, the obstacles were presented and discussed through some sessions in five subsystems of generation and distribution of power, wealth, knowledge, value, and aesthetics. Later, a conceptual model of the ideal system of urban development planning was designed. Then, desirable and executable system changes were identified based on a comparison of the ideal system and the current system, and they were proposed in the form of purposeful activities toward system improvement. Tehran's urban development planning requires a major change in the approach toward planning and solving complex urban problems. This study is an application of systems thinking approaches in learning in practice and managing the complexity of the diversity of views of urban planners in the experience of urban development planning in Tehran.

Keywords

Urban development planning, Soft systems methodology, Formulating the mess, Tehran municipality.

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*Corresponding author
Email: alinasiri2@yahoo.com

1. Introduction

Formulation of Tehran's urban development plan based on urban development approaches and through the determination of prospects, missions, core values, macro goals, and selection of a proper planning model is undertaken in expert committees of organizations, companies, and the headquarters of the 22 districts of Tehran Municipality (Performance Report of the Third Municipal Program of Tehran, 2022a). Four urban development plans have been formulated and executed for Tehran so far. The structure and principles regarding the formulation of the fourth plan are composed of the supreme group, the leading and integrating council, the planning secretariat, expert committees, the scientific committee, and workgroups from the 22 districts, which are entrusted with the task of studying and examining the current status, formulating solutions, determining strategic goals, policies and principles of the plan, enumerating the indices, evaluating, pursuing approvals procedure and documenting the plan (Tehran's fourth urban development program formulation regulations, 2022b).

This study conducted a problem-oriented systems intervention using SSM by proposing a learning-by-doing procedure and analyzing the obstacles to developing a system for formulating Tehran's urban development planning inspired by formulating the mess by considering the varied viewpoints of the participants in planning formulation.

Formulating the mess analyses the obstacles in identifying dysfunctions in the aspects of how power, knowledge, wealth, aesthetics, and value are generated and distributed in a social system and is based on the following principles: 1. No social system can consume more than it produces in the long run. Wealth distribution without effective production results in poverty (generation and distribution of wealth); 2. Management of social systems requires understanding and consensus about the regulations of decision-making and the why and the reasoning of affairs (generation and distribution of power); 3. The success of any social system ultimately depends on its capability to generate and distribute the knowledge a learning system requires (generation and distribution of knowledge); 4. The effectiveness of an organization depends more on the management of the interactions between its members than on the activities (generation and distribution of values); 5. Effective membership in a social system requires a role, a sense of belonging, and faithfulness to participate in creating the future (generation and distribution of aesthetics) (Gharajedaghi, 2015). SSM is an action-research approach for learning purposeful human systems in complicated problem situations. This methodology analyses the problem situation from a holistic, systemic approach and fosters group learning from the experience of the participants and those involved in the problem in the form of

conceptual models by proposing a learning-by-doing procedure. It is considered a systems approach and research on soft operations, which entails significant successes in managing the complexity of different viewpoints from the stakeholders involved in the problem (Masys, 2016).

This literature review focused on two lines of studies: urban development planning in Tehran Municipality and the literature on the application of the Soft Systems Methodology.

As for the line of urban development planning in Tehran Municipality, Faizi and Barak pour (2022) evaluated the development plans for the metropolis of Tehran and its suburbs by focusing on the implications of climate change and indicated that Tehran's urban development plans lacked sufficient emphasis on the influences of climate change. Kamanroodi et al. (2021) analyzed the identity and branding orientations in Tehran's urban development plans. Molaei et al. (2018) evaluated the efficiency of participatory management in Tehran's urban development planning and indicated the drawback on the part of participation from non-governmental organizations, the private sector, and the public. Ebrahiminia and Abdi Daneshpour (2017) referred to failure in reaching consensus among the policy-making agents about maintaining integrative policy-making principles, negligence or oversight of the mutuality of formal and informal elements as well as the absence of a continuous planning process for decision-making as the most important causes of disintegration in Tehran's policy-making.

In an investigation into the applications of SSM in urban management and planning issues, Shahrabi Farahani et al. (2022) designed an alignment pattern of program and budget in Tehran Municipality. They indicated the lack of association between program and budget in Tehran Municipality under the influence of intra- and inter-organizational root causes such as lack of supporting regulations, weakness in the budgeting system, poor program structure, weakness in the mechanisms of intra- and inter-organizational monitoring on program and budget, financial and accounting weaknesses, infrastructural requirements and lack of coordination between stakeholders. Using SSM, Benz, and Stafacher (2023) analyzed the problem of changing Swiss railroad stations, taking into account the gap between the short-term local worldview and the long-term national worldview. Lin et al. (2022) designed Gwangju's urban economic development model and proposed recommendations for planning the urban development of pioneer industries. Markou (2022) addressed sustainable urban management of flooding threats. Wang and Roon (2021) analyzed urban management strategies for storms. Wang et al. (2021) designed a model for planning suburban identification and its expanding patterns in Harbin, China. Zhang and Chen (2021) explored urban management of water quality under the threat

of an unanticipated storm. Qiao et al. (2019) investigated the governance factors involved in the sustainable management of stormwater and developed a model in consensus from the perspectives of four cities in China and Sweden. Sarawat et al. (2017) modeled the scenario of integrative urban water management for sustainable water governance in the Kathmandu Valley, Nepal.

Schilder (2016) designed the supporting systems of planning in urban development in the Netherlands, and Romero-Garcia et al. (2015) designed a model of a sustainable urban tourism system in Mexico City. Suriya and Moodgal (2013) addressed the integrative management of floods in their studies on catchment basins in Adyar, Chennai, India, using SSM. Jeppesen (2011) explored the open use of the concept of sustainability in transport planning, and Coelho et al. (2010) designed the supporting structure of decision-making in urban energy planning. Nasiri et al. (2022) developed the system of corona disaster management in Tehran Municipality using the mixed approach of SSM and Social Network Analysis (SNA). Delima Modiroos et al. (2020) analyzed land facility development on the basis of the regional geographical capacity in Brazil. They revealed the complicated requirements, the ambiguous relations, the conflicts of interest, and the integrated solutions of the involved institutions. Nguyen et al. (2019) designed a framework with the purpose of using SSM that revealed the local community's understanding in order to mend the ecology based on different viewpoints stemming from the main stakeholders' and decision-makers' perceptions using SSM. The review of studies shows the wide application of SSM in the management of stakeholders with diverse views on a wide range of urban problems.

A review of the literature indicated that despite the wide applications of systems methodologies in solving complicated urban problems, the studies in urban development planning are highly limited in Tehran Municipality. Furthermore, despite the emphasis placed on the lack of consensus on urban management development policymaking and the suggested challenges and obstacles, holistic, systemic studies in this regard have not been the focus of attention. Therefore, this study proposed learning in action to conduct a problem-oriented systemic intervention using SSM and, inspired by the formulation of the mess theory; the social system development obstacles were structured under five subsystems of generation and distribution of wealth, power, value, knowledge and aesthetics, and, using the soft systems approach, not only was a model of an ideal system of plan formulation designed but the expandable points of the mid-term plan formulation system in Tehran Municipality were also identified. This study was carried out in Tehran Municipality in 2023.

2. Methodology

The SSM steps include the following: 1&2. Confronting the Problem Situation: This step encompasses entrance into the problem situation and identification of persons, culture, standards, and the values governing the situation through interviews, discussions, brainstorming, and representative illustrations; 3. Developing Root Definitions: Root definitions are the statements that define an ideal system, its goals, and the persons who would be involved in it; 4. Developing a Conceptual Model: A diagram of all the activities and the connecting lines between them is developed; 5. Comparing the Model with the Real World: This step involves comparison of the models with what actually happens in the real world; 6. Identifying and Determining the Required Changes: This step includes systematic determination of the desirable changes that are also culturally practicable in the real world; and 7. Executing: In this step, the changes determined in the previous step are executed in practice (Jackson, 2019). The research data was collected using supporting documents on Tehran city planning, previous critical studies, and group interviews with planners. The research community was identified among the principal elements of Tehran's fourth plan formulation supreme group. Table 1 presents the descriptions of a number of select participants in the research.

Table 29. Descriptions on the research participants selected from the key actors of the supreme group formulating Tehran's fourth plan

No	Education	Expertise	Experience (years)	Specialization
1	PhD.	Public administration	20	Supreme group of planning/Leading and integrating
2	Masters	Environmental Engineering	22	Supreme group of planning/Leading and integrating
3	PhD.	Accounting	17	Resources and consumptions
4	PhD.	Health disasters and emergencies	20	Safety and disaster management
5	PhD.	Economy	4	Finance and urban economy
6	Ph. D.	Political geography	8	Management development
7	Masters	Management	20	Urban services and environment
8	Masters	Information and communications technology	19	Intelligentization and information technology
9	PhD.	Public administration	20	Human capital
10	PhD.	Management	14	Management development

3. Findings

The research findings are explored following the steps of SSM.

3.1. Steps 1&2: Confronting the problem situation

The first two steps explored the problem situation of the system of formulating Tehran's urban development planning based on the documents provided by the supreme group responsible for

formulating Tehran's fourth urban development plan and the actors' actions and minutes and enactments of expert committees' meetings on formulating Tehran's fourth urban plan. In order to determine the boundaries of the study, as shown in Figure 1, the system boundary and the system input and output were determined in agreement with the stakeholders. As observed here, at the level of Tehran's comprehensive planning system, Tehran Municipality, and Tehran's Islamic City Council are responsible for the management of the system. System inputs are taken into consideration based on upstream reference documents, enactments communicated by the Islamic City Council of Tehran, the pyramid of organizational responsibilities of the units involved in the problem in Tehran Municipality, and the organizational resources, facilities, capacities, and capabilities available. The system of interactions between actors is addressed based on the responsibility structures in a supreme group of Tehran's fourth urban development planning and the series of actions taken by the actors in this group. Ultimately, the system output is the formulation of Tehran's fourth urban development plan. The system boundary encompasses a collection of actions and interactions by the actors in the supreme group of Tehran's fourth urban development plan. The formulated plan in the total system of Tehran's urban planning has passed the fourth plan's approval procedure in collaboration with the Program, Budget, and Accounting Commission as well as the other expert commissions in the Islamic City Council of Tehran. This study focused on the viewpoints put forth by those involved in formulating the plan in Tehran's fourth urban development planning supreme group.

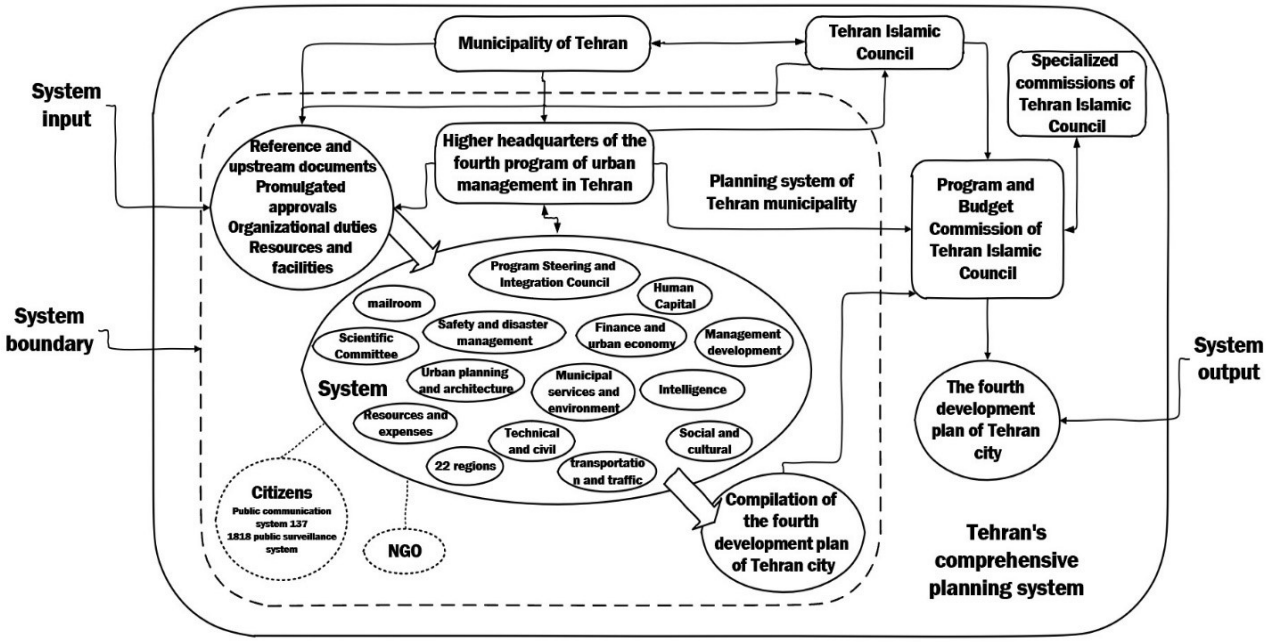

Figure 55. Definitions of the system of formulating Tehran's fourth urban development

Afterward, through interviews and discussions with the fourth plan formulation experts, the problem situation and the current structure of formulating urban development plans in Tehran Municipality were explored. With the help of the intervention team, a rich picture of the situation of the system of formulating Tehran's urban development plans was drawn, and discussions around the problem situation of the system of formulating plans and development areas were formed on that basis. The illustration gave the participants the opportunity to gain insight into the important causes and their relationships from the viewpoint of the other participants and the ground for the creation of a common representation of the system of formulating Tehran's urban development plans could be fostered. Figure 2 indicates the rich picture of the problem of the system that is formulating Tehran's urban development plans.

As shown in the figure, the actors of this system are the Islamic City Council of Tehran and Tehran Municipality as the principal owners of the problem and the actors of the system, the principle elements of plan formulation in line with the structure of the supreme group of Tehran's fourth urban management plan, including the program leading and integrating council, expert committees, resources and consumptions committee, science committee and workgroups of the 22 districts of Tehran Municipality. The clients of the system of formulating Tehran's urban development plans are Tehran's citizens, Tehran Municipality's employees, the public sector, the private sector and non-governmental organizations. The citizens of Tehran, as the victims of inefficiency of Tehran's urban development plan formulation system, are facing an increase in urban problems that urgently need to be addressed.

In this systemic intervention design, Tehran Municipality aims to develop the system of formulating Tehran's urban development plan based on recording lessons learned from the key actors of the supreme group responsible for formulating Tehran's fourth urban development plan so that the grounds for developing planning processes will be fostered in similar planning experiences.

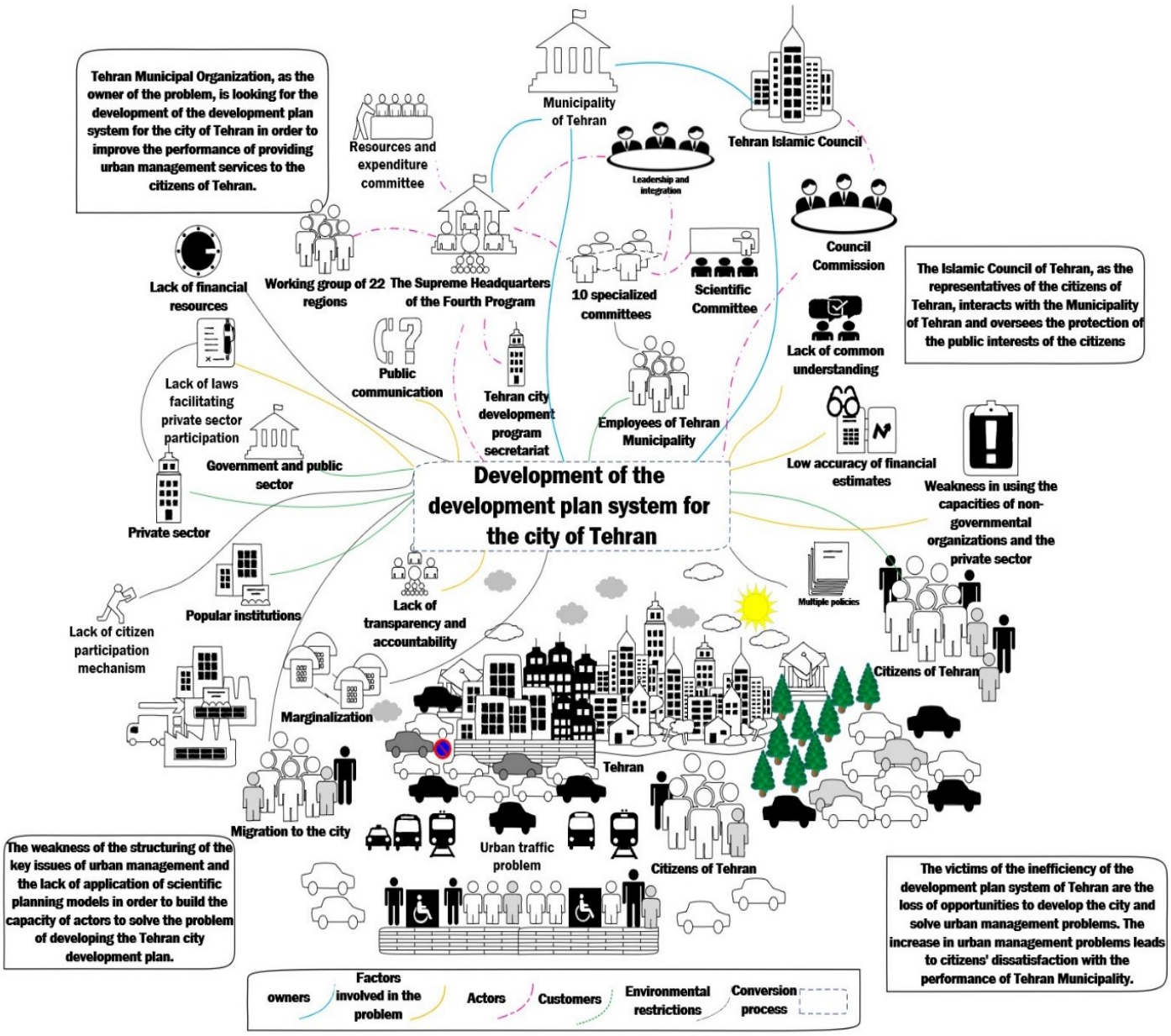

Figure 56. Rich Picture of the problem of Tehran's urban development plan formulation

3.2. Step 3: Developing root definitions

A root definition is a statement describing an ideal system, its objectives, and those involved in it. A technique called CATWOE is applied when developing root definitions. The analysis results are presented in Table 2. Then, using the opinion and consensus from the stakeholders, the problem of developing a system of Tehran's urban development plan formulation was analyzed, and an agreed-upon root definition was developed.

Table 30. CATWOE components of the system of Tehran's urban development plan formulation

CATWOE	System of tehran's urban development plan formulation
Customers	Tehran's citizens, Tehran Municipality employees, executive institutions, Tehran's public sector, Tehran's private sector businesses, Tehran's non-governmental organizations
Actors	Supreme group of formulating Tehran's fourth urban management plan; Tehran's mayor; program leading and integrating council; program secretariat; resources and consumptions committee; scientific committee; specialized committees for formulating programs including the financial and economic committee of the city; human capital committee; management development committee; intelligentization committee; urbanism and architecture committee; safety and crisis management committee; environment and urban services committee; technical and constructional committee; transportation and traffic committee; social and cultural committee; Tehran Municipality workgroups of the 22 districts; representatives of Islamic City Council of Tehran; program, budget and accounting commission of Islamic City Council of Tehran; expert commissions of Islamic City Council of Tehran
Transformation	Development of the system of Tehran's urban development plan formulation
Worldview	The main obstacles in the development of social systems are caused by the malfunctioning of one or all five dimensions of social systems (generation and distribution of wealth, power, value, knowledge, and aesthetics). With regard to the analysis of development obstacles, formulating the mess leads to a new way of looking at the structuring of social system issues and creating system development opportunities.
Owners	Tehran's Islamic City Council and Tehran Municipality
Environmental Limitations	The absence of an integrated governance structure of urban management at the macro level of the country; the rising trend of issues and problems of Tehran city; lack of credits and financial resources available for the urban development plans of Tehran; absence of a suitable mechanism for citizens' participation toward the realization of Tehran's urban development plans; lack of laws facilitating private sector participation; multiple and sometimes contradicting urban management policies in the governmental, public and private sectors of the country

3.2.1 Analysis of obstacles in development of system of tehran's urban development plan formulation

For the ideal system's dimension to be analyzed, first, the obstacles in the development of the system of Tehran's Urban Development Plan Formulation were extracted, taking into account the examination reports of the previous programs and the documents on Tehran's fourth urban development plan formulation. Then, in a semi-structured interview session, the list of the obstacles to Tehran's fourth urban development plan formulation system was presented to the participants, and they were asked to identify the most important obstacles in the Tehran Municipality situation. The identified obstacles were discussed through some meetings, and 37 obstacles agreed upon by all of the participants were determined under five subsystems based on the content analysis of participant opinions. Table 3 presents the obstacles to the development of Tehran's urban development planning formulation system.

Table 31. Obstacles in developing Tehran's urban development plan formulation system

Obstacles in the subsystem of generation and distribution of wealth	**Symbol**
Shortage of sustainable sources of income for Tehran and limitation of financial resources for Tehran Municipality	**W01**
Insufficient flexibility in supplying the costs of implementing the program vs. variations in the economic environment of the country and Tehran Municipality	**W02**
Insufficient conformity of Tehran Municipality's annual budgets with the resources predicted in Tehran's urban development plans	**W03**
Low accuracy of the financial estimates of the table of resources and consumptions of Tehran's urban development plans	**W04**
Weakness of Tehran Municipality's budgeting system	**W05**
Obstacles in the subsystem of generation and distribution of power	**Symbol**
Weakness in the planning structure and lack of integration in the institution responsible for planning and managing Tehran's urban development	**P01**
Uncertainty, lack of understanding, and collective agreement on the decision-making criteria of the principles of formulating Tehran's urban development plan	**P02**
Unclear mechanisms of approval, control, surveillance, and implementation in a number of provisions of Tehran's urban development plan	**P03**
Inadequate stability of urban management and change of program priorities during the implementation of Tehran's urban development plan	**P04**
Communicating some tasks without considering the limits of Tehran Municipality's duties and powers in Tehran's urban development plan	**P05**
Inefficiency of regulations in guaranteeing the proposed plans for Tehran's urban development	**P06**
Failure to determine the role of the organizations involved and the existence of multiple and common trustees in the public sector and public institutions	**P07**
Obstacles in the subsystem of generation and distribution of value	**Symbol**
Lack of focus on creating common values for the stakeholders of Tehran's urban development plan	**V01**
Conflict of interest and management of ineffective conflict between the interactions of actors in Tehran's urban development plan	**V02**
Lack of common understanding, ambiguity, and lack of agreement in the concepts and provisions, clauses, and indicators of Tehran's urban development plan	**V03**
Failure to form a collective agreement based on the establishment of integrated policy-making principles of Tehran's urban management	**V04**
Multiple and sometimes contradicting policies of urban management in the public and private sectors of the country	**V05**
Lack of attention to the effects and consequences of program implementation on the level of Tehran citizens' satisfaction	**V06**
Obstacles in the subsystem of generation and distribution of knowledge	**Symbol**
Weakness in the structuring of key issues and the capacity to solve the problems of Tehran's urban development plan	**K01**
Failure to use scientific planning models in developing strategies and policies for Tehran's urban development plan	**K02**
Weakness of a systematic and meaningful connection of the perspective, strategies, and policies with the materials and provisions of Tehran's urban development plan	**K03**
Lack of establishment of knowledge management system in key issues of Tehran Municipality	**K04**
Weakness in predicting possible risks in realizing the key assumptions of formulating Tehran's urban development plan	**K05**
Lack of scenario planning based on possible risks and, as a result, lack of design of appropriate response according to possible scenarios	**K06**
Lack of coherent studies on the feasibility of plans and projects of Tehran's urban development plan	**K07**
The lack of a suitable and reliable statistical system for formulating Tehran's urban development planning	**K08**

Failure to prioritize plans, projects, and measures according to the strategies, policies, and provisions of Tehran's urban development plan	**K09**
Weakness in the scheduling of the program and the density of tasks foreseen in the program provisions in the first and second years	**K10**
It is not possible to measure the process of qualitative changes in some of the provisions of Tehran's urban development plan	**K11**
The existence of some abstract, unrealistic, and idealistic provisions in Tehran's urban development plan	**K12**
Obstacles in the subsystem of generation and distribution of aesthetics (social coherence)	**Symbol**
The inefficiency of the effective membership of all key actors, including the role definitions in the program to create a sense of belonging and commitment and participation toward creating the future of Tehran	**A01**
Weakness of motivation, commitment, and adherence to the plan among the actors involved in urban development planning in Tehran	**A02**
Lack of inter-institutional cooperation and coordination and realization of integrated urban management	**A03**
The absence of private sector participation mechanisms toward the realization of Tehran's urban development plan	**A04**
Weakness in using the capacities of non-governmental organizations and the private sector	**A05**
Inconsistency in the system of urban development planning and local development planning	**A06**
Absence of citizen participation mechanisms toward the realization of Tehran's urban development plan	**A07**

The majority of the obstacles fall under the subsystem of generation and distribution of knowledge, which has 12 obstacles. The next largest subsystems are the generation and distribution of power and those of aesthetics, with seven obstacles each. Moreover, the subsystem of generation and distribution of value with six obstacles and the subsystem of generation and distribution of wealth with five obstacles were identified. At this point, taking into account the obstacles in developing the system of Tehran's urban development planning, the ideal system of formulating Tehran's urban development plan was identified with regard to the relative consensus between the key actors.

3.2.2 Components of the ideal system of tehran's urban development plan formulation

Considering the discussed points, the components of the ideal system of formulating Tehran's urban development plan were identified and presented in Table 4 in conformity with the five subsystems.

Table 32. Components of the ideal system of formulating Tehran's urban development plan

Obstacles Components of the subsystem of generation and distribution of wealth
Existence of sustainable sources of income for Tehran Municipality
Determining the position of Municipality in the financial and economic area of Tehran
Designing economy prediction models for Tehran
Realistic financial estimates of the table of resources and consumptions of Tehran's urban development plans
Efficient budgeting system of Tehran Municipality
Compliance of financial resources with the government's annual budgets considering the dependence of the program on the government's obligations
Flexibility of financing program implementation costs in the economic environment of the country and Tehran Municipality
Components of the subsystem of generation and distribution of power
Efficiency of the macro-planning structure of the country's development and its connection with urban development plans
Efficiency of governance structure of integrated urban management
Analyzing the stakeholders and determining the role of the involved organizations and the responsibility of each transparently in the public sector and government institutions
The existence of legal mechanisms to facilitate the regulatory role of the government in the allocation of resources and relations of the cooperation network of actors to solve urban problems
Paying attention to the limits of duties and powers of Tehran Municipality in solving the problems of Tehran
Collective understanding and agreement on the role and legal position of the organizations under Tehran Municipality in solving the problems of Tehran
The existence of conflict of interest management mechanisms among the interactions of the actors involved in formulating Tehran's urban development plan
Designing the approaches of the collective agreement of the municipality and Islamic City Council in structuring the framework of Tehran's urban development plan
Clarity of the framework of the executive process and the mechanisms of approval, control, supervision, and execution of provisions in formulating Tehran's urban development plan
Meritocracy and stability in urban managers in Tehran's urban planning process
Mechanisms of transparency, accountability, and adequate monitoring of the performance of urban managers
Coordination in the system of urban development planning and local development planning
Components of the subsystem of generation and distribution of value
Focusing on the creation of common values of the stakeholders toward creating the future of Tehran
The formation of a collective agreement based on the establishment of the principles of integrated policy-making of Tehran's urban management
Changing the attitude of urban managers from a temporary and short-term approach to solving the root problems of Tehran
Common understanding and agreement on concepts and provisions, clauses and indicators of Tehran's urban development plan
Paying attention to the effects and consequences of program implementation on the general well-being of the society and the satisfaction of the citizens of Tehran
Components of the subsystem of generation and distribution of knowledge
Identifying and structuring key issues according to the intertwined and complex urban issues
Paying attention to the use of scientific methods to achieve collective agreement in order to increase the problem-solving capacity of the actors involved in Tehran's issues
Applying scientific models of problem-oriented planning in formulating strategies and policies to solve problems in Tehran
Systematic studies of the city's key issues, from structuring and identifying the root causes to reaching solutions proposed to solve the problems
Statistics system and appropriate and reliable information banks for planning key issues of Tehran
Modeling and simulating complex urban problems and identifying systemic problem-solving solutions
Forecasting possible risks in realizing the key assumptions of proposed solutions and scenario planning and formulating alternative solutions
Establishment of the knowledge management system to solve key issues in Tehran
Creating a communication network and continuously exploiting the capacity of academic elites, urban planning consultants, and Tehran Municipality experts
Coherent feasibility studies of proposed plans and projects in Tehran's urban development plan

Prioritization of plans, projects, and strategic actions of Tehran's urban development plan
Providing the possibility of measuring the progress of the program and determining the effectiveness of the program's progress in solving Tehran's issues
Dissemination of information and transparency of the municipality's performance in advancing the solution of Tehran's problems
Informing and making citizens aware of the root causes of urban problems and sharing suggested solutions
Components of the subsystem of generation and distribution of aesthetics
Effective membership of key actors, including role definitions, in the program to create a sense of belonging and commitment toward creating the future of Tehran.
Participation and inter-institutional coordination to realize the integrated management of Tehran.
Coordination and framing of the planning structure based on the collective agreement of the municipality and the Islamic City Council of Tehran
Incentive policies of employee participation to make them motivated and committed to the program among development planning actors in Tehran
Predicting efficient performance evaluation systems for urban employees and managers
Citizens' general trust in Tehran Municipality's decision-making and plans
The existence of the participation mechanism of citizens and the private sector in the realization of Tehran's urban development plan
Incentive policies for citizen participation and utilizing the capacity of the private sector and non-governmental organizations.

3.3. Step 4: Developing a conceptual model of an ideal system of formulating tehran's urban development planning

The ideal system of Tehran's urban development plan formulation encompasses components that Tehran Municipality considers with the purpose of developing the system of plan formulation in an ideal system. As was also mentioned, the development of the ideal system was achieved by considering the understanding, perception, and mental model of the research participants on the experience gained in formulating Tehran's fourth urban development plan and extracting the tacit knowledge of managers through an intervention process and semi-structured interviews. The system intervener drew conceptual models of system development based on the perception of the problem situation, content analysis, and extraction of themes from the interviews of the participants, eventually finalizing the extracted models through a verification procedure.

Accordingly, given the components of an ideal system of Tehran's urban development planning formulation, it was designed based on five mess formulation subsystems, including the subsystems of generation and distribution of power, wealth, value, knowledge, and aesthetics. It was assured that the perceptions of the key actors involved in the problem would be extracted in a format conforming to the concepts of the ideal system.

Figure 3 illustrates the conceptual model of developing the ideal system of Tehran's urban development planning formulation. Since the modeling procedure is a learning cycle, the modeling procedure of the ideal system of Tehran's urban development planning formulation requires that the performance of Tehran's urban development planning formulation be evaluated

based on the ideal system, the criteria of efficiency and effectiveness be determined in each stage, and the quality of implementing the solutions of developing a system of plan formulation be monitored so that the planning progress can be analyzed with the expectation of solving the problem.

It is also necessary that controlling measures be examined for identification of implementation obstacles, an evaluation be conducted taking into account the changes and the environmental limitations over appropriate intervals, and the components of the ideal system also be evolved in a learning cycle. Furthermore, a set of five criteria (5E) of efficacy, efficiency, effectiveness, ethics, aesthetics, and delicacy were evaluated based on the evaluation criteria of conceptual models by asking a number of questions from the participants, and the key actors confirmed them through a verification procedure.

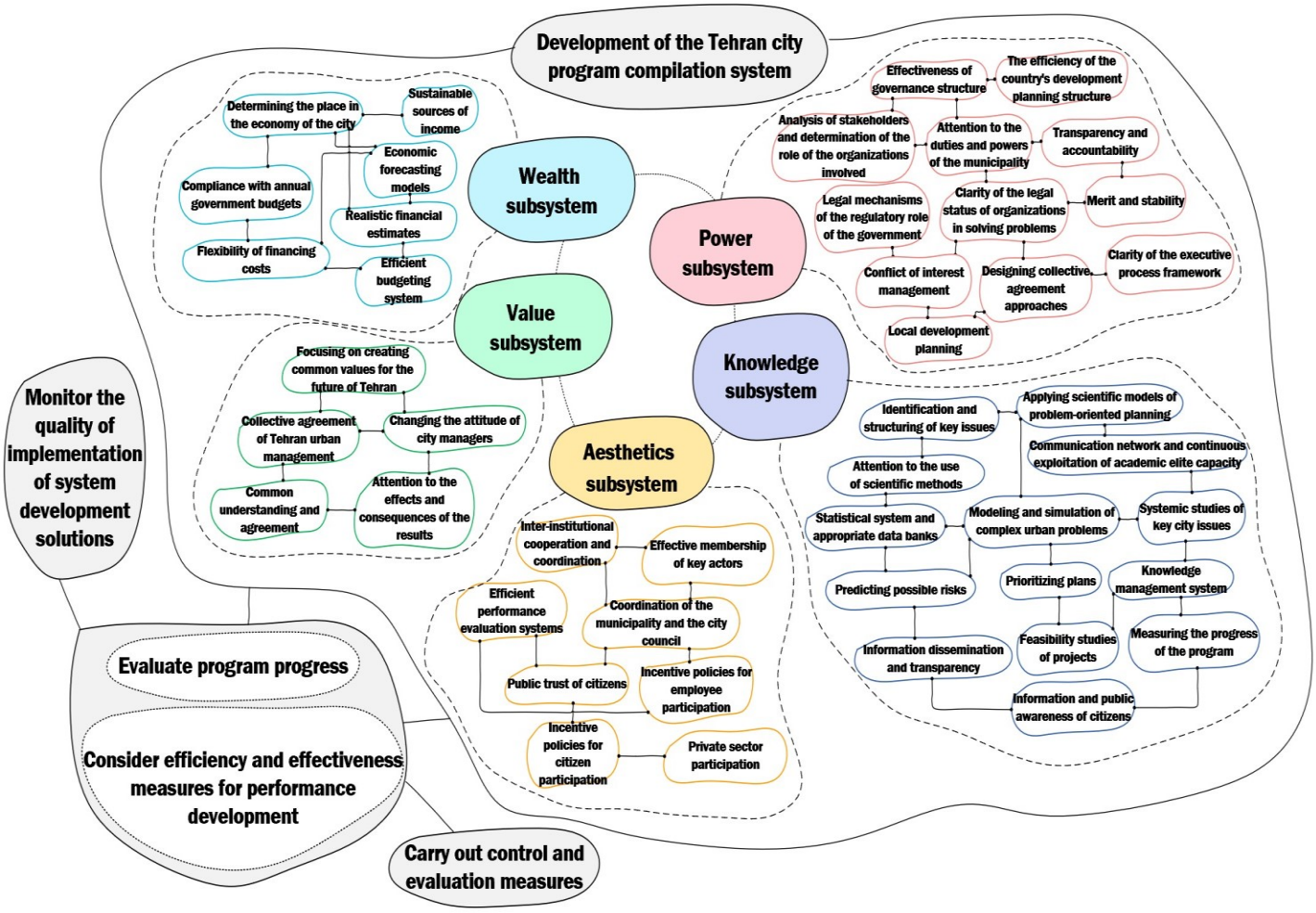

Figure 57. Model of developing the ideal system of Tehran's urban development planning formulation: Source: research findings

3.4. Step 5: Comparing the model with the real world

The model was compared with the real world in accordance with the four analyses put forth by Checkland (1990): First Comparison) Based on the developed conceptual model, prior to the presentation of the model to the participants, a number of questions were issued by the intervener, and discussions on the necessity of change were carried out among the key actors in formulating Tehran's urban development plans; Second Comparison) In this comparison, the conceptual model was analyzed by referring to the structure of urban development planning formulations programmed before; Third Comparison) The Developed conceptual model was presented to the participants, and the comparison was made with regard to the current situation of plan formulation in Tehran Municipality; Fourth Comparison) The details of the conceptual model of the ideal system were examined and compared with the details of what presently exists, and the overlaps between the conceptual model and the current real model were identified.

3.5. Steps 6&7: Identifying desirable systemic and culturally feasible changes and executing them

In the next step, possible changes were defined according to the gap between the current and ideal situation with the participation of experts. The two final stages emphasize the importance of maintaining two logical and cultural trends: the logical trend addresses the importance of the validity of the conceptual model in the form of systemic thinking, and the cultural trend considers the decision-making regarding the implementation of desirable systemic changes to require commitment and agreement between the key stakeholders. To this end, it was ensured that the proposed changes and solutions were in line with the existing development plans and facilities. The results of these steps are presented in the discussion section.

4. Discussion

Based on the research findings, the following practical suggestions for developing a system of formulating Tehran's urban development planning are proposed as follows:

The efficiency of the integrated urban governance structure with emphasis on the regulatory role of the government

Considering the inefficiency of the urban management governance structure, it is suggested that the follow-up of a comprehensive urban management plan be placed on the agenda and, accordingly, participation in revisiting the upstream laws in order to realize the integrated urban

management based on the regulatory role of the government in dedicating resources and the relationships in the cooperative network of urban management actors be realized.

Follow-up and negotiation for the alignment of the urban development plans with the country's development plans

Considering the inefficiency of the country's development macro planning structure and the absence of a meaningful connection between the urban development plans, it is suggested that, while making efforts to strengthen the relationship between the macro policies of the municipality and Tehran's urban development plans with the macro policies of the country's development plan, the actors of the plan development in Tehran Municipality follow up and negotiate with the key actors of development plans of the country in order to establish the legal position of the municipality in determining the roles and responsibilities of the program and create legal support for the coordination and communication of the key actors of the development plans.

Creating an inter-institutional cooperation network and planning negotiations with key stakeholders on the key issues

Considering the complexity and intertwining of urban issues, it is suggested that the stakeholders be analyzed and the role of the involved organizations and the duties of each in the key issues of Tehran be determined in the public sector and the government institutions of the country. Moreover, according to the power and influence of each of the actors in solving the issues, the planning of negotiations and the creation of an inter-institutional cooperation network should be addressed.

Planning the approaches of the consensus reached by the municipal planners and the Islamic City Council in the structuring of the plan formulation

Considering the challenges that exist in the process of program approval, it is proposed that in order to have a common understanding of the planning framework for the urban development of Tehran, the decision-makers of the Islamic City Council be involved in the plan formulation procedure from the beginning of structuring the urban development plan framework through a soft system intervention process so that the representatives who participate in the specialized committees for formulating the plan are also the appraisers of the plan in the process of approving the plan in the Islamic City Council so as to prevent later fundamental changes.

Strengthening mechanisms of transparency and accountability for the performance of city managers

A lack of transparency and insufficient monitoring of the performance of city managers during the program will cause a challenge in achieving the goals. Hence, strengthening transparency and accountability through the publication of the performance report of city managers toward solving the key problems of the city, according to the public and private revenues at the disposal and the expenses of the units under management and how the development resources are spent toward realizing the plan, is highly recommended. In addition, it is intended to recognize the right of financial supervision of the Islamic Council of Tehran and the supervision of the Islamic Council and other supervisory institutions.

Absorbing sustainable sources of income for Tehran Municipality

Considering the limited sources of sustainable income and the fact that Tehran Municipality's income falls short of city duties and taxes, as well as the high dependence on government obligations, it is suggested that Tehran Municipality identify and evaluate the system of absorbing sustainable sources of income. In addition, by pursuing the legal approvals of providing financial resources and presenting analytical reports of the city's issues, and on the basis of negotiation and persuasion, it is expected that they explain the financial relationship between the government and the municipality in order to solve the city's issues.

Determining the position of the municipality in the field of finance and economy of Tehran city

Due to the uncertainty of Tehran Municipality's position in the area of finance and urban economy and considering the lack of experts in this field, it is suggested to recruit specialized experts and qualified economic consultants to design an estimation model of the gross production of Tehran city and prepare an input-output table of Tehran city.

Designing prediction models of Tehran's economy

Given the absence of basic information on the urban economy, it is suggested that income and expense prediction models of the Municipality be accurately estimated by updating the information and data on the urban economy. As a result, the consequences of macro decisions on the economy of Tehran will be predictable, and the table of resources and expenses of the program based on prediction models will be developed in a scientific and realistic manner.

Redesigning the budgeting system of Tehran Municipality

Considering the inefficiency of the budgeting system and the lack of alignment between the plan and the budget, it is suggested that the budgeting system of Tehran Municipality be redesigned while integrating the budget systems and updating the cost data. In this vein, the compliance of the municipality's financial resources with the government's annual budgets should also be taken into account.

Flexibility of financing the costs of implementing the program with regards to the uncertainty of the economic environment

Although generally, the effects of inflation on the amount of income sources and the current and implementation costs of the program are normally considered based on the continuation of the previous process while developing the program, it is suggested that, in addition to financial planning based on economic prediction models, the value of Tehran Municipality services be engineered. Some research efforts must be made in order to improve the efficiency of the services value chain. In addition, economic analyses of cost reduction based on possible scenarios should be planned.

Identification and structuring of key issues with regard to the intertwinement and complexity of urban issues

Considering the axiomatic position of the actors involved in the planning formulation regarding the causes and solutions of urban issues, it is suggested to first identify and analyze the communication network of Tehran city issues and the statistics of the key issues according to the results of the network analysis and then to consider the typology of the complexity of the key issues in Tehran.

Capacity building for solving Tehran's problems by the key actors

Considering that the agreement on the dimensions of urban issues has been created only at the level of the principles of the planning formulation, it is suggested to plan a soft system intervention with all the key actors to enhance the capacity of the solutions to urban issues, including the government, the public, and the people's sectors.

Applying scientific models of problem-oriented planning in formulating strategies and policies to solve the problems of Tehran

Despite the emphasis on the main problem, the program formulation lacks a problem-oriented planning model. It is suggested that systematic studies of the causes and suggested solutions to

solve complex problems be carried out with the participation of academic elites and Tehran Municipality experts.

Creating a suitable and reliable statistics system and data banks for planning the key issues of Tehran

Due to the lack of appropriate statistics and information for researching and analyzing the urban issues of Tehran, it is suggested that while designing an information system of Tehran's key issues, the required databases be identified and the suitable and timely data and information to support decision-making based in the design of the information systems be collected.

Modelling and simulation of complex urban problems and identification of systemic solutions to the problem

Considering the absence of supporting models for decision-making and simulating the situation of key problems in Tehran, it is suggested that systems modeling studies of complex problems in Tehran be carried out. Implementation and decision-making support models should be made based on simulating the problems, testing the strategic assumptions of the actors on the model, and problem behavior analysis.

Predicting possible risks in realizing the key assumptions of the proposed solutions and scenario development and planning of alternative solutions

Considering the lack of program risk management and the absence of alternative scenarios for solving the key issues, it is suggested that while revealing the strategic assumptions in solving the key issues agreed by the actors, the risk management and development of varied scenarios and alternative solutions should be conducted.

Establishing a knowledge management system for solving key issues in Tehran

Considering the importance of knowledge management in building the capacity to solve complex problems, it is suggested that the specialized knowledge areas of urban management issues be identified and that the knowledge management system for urban issues in the subsystems of Tehran Municipality be designed. In the process of organizational planning, the experiences of managers in the implementation of the documentation program, as well as the tacit knowledge, should be recorded in the organization's knowledge management system. In addition, it is recommended that the successful experiences and initiatives in the cities of the country in solving the problems of metropolises be evaluated and reviewed, as well as the successful experiences of the neighboring countries in solving urban problems.

Creating a communication network and continuously exploiting the capacity of academic elites, urban planning consultants and experts of Tehran Municipality

Given the lack of proper use of the capacities of urban planning specialists and consultants, it is suggested that the processes of employing specialized academic and professional consultants in the study and planning center of Tehran city be made agile and while expanding the range of research associates and organizational consultants, focus should be on ensuring the efficiency of the selection process of competent consultants. It is also emphasized to establish that a stable cooperation relationship be established and to train that specialized organizational consultants be trained in order to increase problem-solving capacity.

Coherent studies of project feasibility and the requirement to prepare environmental and social safety and passive defense annexes for the macro projects of the Tehran city development program

Considering the insufficient studies conducted on the feasibility of the proposed plans and projects, it is recommended that feasibility studies be conducted on the proposed metropolitan plans and projects. These studies would necessitate the preparation of environmental and social safety and passive defense annexes by independent consultants, along with the necessary monitoring and evaluation mechanisms and the required executive guarantee.

Prioritization of plans, projects and strategic measures of Tehran's Urban Development Plan

Considering the lack of prioritization of the plans and measures presented in Tehran's urban development plan, the plan prioritization framework based on multi-criteria decision-making methods should be used to determine the degree of importance of the program's provisions.

Dissemination of information and transparency of the municipality's performance in advancing the solutions to Tehran's problems

Considering the limited number of reports published by Tehran Municipality, it is suggested that efficient systems of evaluating and monitoring the program's performance be designed and that realistic performance reports on the program's progress be published in a timely manner to solve urban problems.

Providing information and raising public awareness of the root causes of urban problems and sharing the suggested solutions

Considering Tehran's key role in solving urban problems, appropriate content should be

prepared and produced according to this role and published in public communication channels to inform citizens. Citizenship and family-oriented education systems focused on Tehran's key issues should also be designed.

Focusing on the creation of the common values of the stakeholders based on the creation of the future of Tehran

Considering the ambiguity in Tehran's future image, it is suggested to create a realistic perspective based on consensus, awareness, and training. Efforts should be made to create common values among key stakeholders in solving Tehran's problems.

Changing the attitude of urban managers from a short-term and intermittent approach to solving the root problems of Tehran

According to the current approach, the managers have a short-term attitude towards solving urban problems. The time-consuming nature of solving development problems, the instability of managers, and the complexity of the problem-solving processes led to the creation of a governing short-term attitude. In order to change this approach, it is suggested that the complexity of the problem situation, the process of solving urban problems, and the performance of city managers in solving complex problems during the years of the program be clarified. In addition, it is suggested to manage the expectations of stakeholders by informing them about the delays and the time-consuming nature of the process of solving complex problems.

Considering the effects and consequences of implementing the program on the general well-being of the society and the satisfaction of the citizens in Tehran

Due to the lack of transparency regarding the consequences of the program on the satisfaction of the citizens and the general well-being, it is suggested to identify the real dimensions of the expectations of the citizens in Tehran from the municipality and to test the results and consequences of the strategic assumptions of the program by using the design of dynamic models according to the dimensions of citizens' satisfaction.

The effective membership of the key actors including role definition in the program in order to create a sense of belonging and commitment toward creation of the future of Tehran

Considering the inactivity of the workgroups of the districts and the neglect of the citizen’s role in the urban development program, it is suggested to address participatory management

based on mutual trust and utilization of the capacities of people, managers, employees, and other stakeholders, and plans should be made for the realization of this partnership at the level of Tehran Municipality's subdivisions, the 22 districts, neighborhood management, and citizens.

Incentive policies for employee participation to foster motivation and commitment the program among the actors of Tehran's urban development planning

Although acknowledging and appreciating the participants in the plan formulation was done by the secretariat of the supreme group of the fourth plan, there is no general incentive policy for all employees. In order to strengthen participation, it is suggested that employees be educated and raised awareness about the role of employees in the process of solving Tehran's problems and that encouraging and supportive laws be introduced for the employees' initiatives in reducing the key problems of the city. In this regard, it is suggested that a detailed reward program based on the participation of the employees of municipal organizations and subdivisions be formulated based on solutions to the key issues of the city.

Strengthening citizens' general trust in Tehran Municipality's decision-making and programs

Considering the lack of a study on the level of public trust in Tehran Municipality, it is necessary to build citizens' trust in the municipality's programs. In this vein, it is suggested to introduce the programs of Tehran Municipality in the mass media to build citizens' trust and promote citizens' media culture to prevent the spread of false news and information and use behavior patterns generally accepted by citizens in guiding public opinion.

Existence of citizens' and private sector's participation mechanisms toward realization of Tehran's urban development plan

Considering the absence of citizens and private sector participation mechanisms in realizing the program objectives and solving urban problems, it is suggested to identify the capacities of the people and the private sector in advancing and solving the key issues of Tehran, hold seminars with the representatives of the private sector of the country, and create an atmosphere of collaborative management.

Utilization of the capacity in the private sector and non-governmental organizations

In order to benefit from the capacities of citizens, the private sector, and non-governmental organizations, it is suggested that knowledge-based companies and start-up businesses be supported in providing creative solutions to urban problems, and basic economic policies should

be designed with support-incentive approaches. In this regard, seminars should be held to provide information on supportive policies.Conclusions

This research has analyzed the obstacles and identified solutions to improve the development program system of Tehran city by compiling the disorder and using the soft systems methodology during a systemic intervention with the practical planning of the learning process. The innovative research method embeds the chaos formula in the methodology of soft systems. In general, the findings of the research indicate that Tehran's urban development planning requires a fundamental change in the approach to planning and solving complex urban problems. This applied research is one of the systems thinking approaches in learning in practice and managing the complexity of the diversity of views of urban planners in the experience of urban development planning in Tehran.

5. Conclusion

This study was an effort to spread problem-oriented approaches to recording organizational experiences and execute the organizational learning process based on modeling Tehran's urban development plan formulation problem.Since no similar research has been done on the issue of planning in Tehran, the dimensions of the problem, and the presentation of solutions in a holistic and systemic approach, it is not possible to compare the results clearly. However, the findings of the current research are in line with the findings of Moulai et al. (2018) regarding the weak participation of non-governmental organizations, the private sector, and people, and the lack of communication between programs and budgets in Tehran Municipality, and the findings of Shahrabi Farahani et al. (2022). In addition, the application of soft system approaches based on agreement and consensus between the diverse perspectives of stakeholders in managing the complexity of urban issues, such as the research of Markou (2022) emphasizes Nasiri et al. (2022) and Delima et al. (2020).

As the present problem is defined at the border of the supreme group system of formulating Tehran's fourth urban management plan, it is possible in future studies to expand the scope of the analysis of the system of formulating the plan and analyze in the problem of plan formulation the views of citizens and actors outside Tehran Municipality, including specialized commissions of the Islamic City Council of Tehran or the other actors who are mentioned as institutional mapping in the program. Considering the identified components of the system of Tehran's urban development plan formulation, it is suggested to consider the relationships between the components of the subsystems of the model, the dynamic complexities of the

development of the identification system, and the causal relationships between the system components in order to design cognitive maps of the system of Tehran's urban development plan formulation. In terms of the key issues, it is suggested that strategic studies be conducted on the basis of the problem. Based on the typology of the complexity of the problem, study teams composed of academic elites, researchers, urban planning consultants, and system analysts should be created. System modeling of the solution should be addressed with group participation appropriate for the problem situations. In future studies, it is suggested that the dynamic model of Tehran's urban planning performance system be designed and strategies and policies to improve the urban planning performance system based on the dynamic system model be identified.Moreover, in order to benefit from the experiences of other countries in urban issues and evaluate and realistically compare the performance of urban management in solving urban issues, it is suggested that in future research, a realistic evaluation of the performance of Tehran Municipality should be carried out. By conducting comparative studies of the performance of urban management, it would be possible to compare and benefit from successful experiences and to find points for improving the effectiveness of the planning system of Tehran. Finally, it seems that problem-oriented and systemic approaches to complexity management in the field of urban management have received less attention from researchers, and it is expected that this research gap be studied by focusing on the challenges of urban management and considering the theories of this field to propose system solutions regarding various problems of urban systems.

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