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Impact of mobility system on sustainable development of polycentric region in developing countries, the case of Mazandaran province, Iran

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by

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Declaration

The author declares all information in this academic work (Ph.D. Thesis) has been independently and originally written and completed to fulfill the Doctor of Engineering (Dr.-Ing.) degree requirement. Also, as required by these rules and conduct, the author has fully cited and referenced all materials and results that are not original to this work.

Shahram Sadeghi

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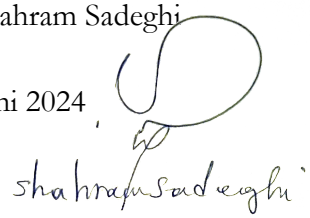

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Abstract

This study investigates the impact of mobility systems on sustainable development in developing countries' polycentric regions, focusing on the interplay between mobility and environmental, economic, and social indicators. To address research questions and validate assumptions, the research utilizes the Mazandaran polycentric province in Iran as a case study, employing a dedicated methodology for its execution.

Distinct indicators have been selected for each aspect of sustainable development. Economic and social indicators are obtained from public statistical resources, while indicators about the environment and the mobility system have been developed due to a lack of publicly available data. The region's urban sprawl trends have been analyzed to address environmental indicators. This involves assessing the negative consequences of sprawl, particularly regarding land use change and urban development, to gather valuable statistics on the utilization of lands and environmental impacts. In addition, the development of the mobility network in the Mazandaran region has been considered for mobility system indicators.

Quantitative and qualitative data on environmental indicators (sprawl) and mobility indicators (area and length of the mobility network) in the Mazandaran region were obtained by analyzing satellite photos from 1995 to 2020. Remote sensing techniques were applied within the Google Earth Engine platform to interpret these photos and extract the necessary statistical data.

The study highlights a substantial correlation between the polycentric structure and the expansion of built-up areas, urban sprawl, land use change, and mobility networks within urban centers. This reciprocal relationship is accelerating environmental degradation in the Mazandaran polycentric region. The increased number of trips between these centers underscores the need to develop mobility infrastructure. Statistical analyses indicate a strong association between economic indicators and the province's mobility network, presenting potential economic prosperity with enhanced mobility. The province witnesses massive land use changes and rural-to-urban

migration linked to transportation network expansion and increased employment opportunities. While the polycentric spatial configuration facilitates migration, contributing to employment growth, the study recognizes the potential instability, cautioning that mass migration could impede long-term sustainable growth in economic and social dimensions.

Keywords: Polycentric, Mobility, Sprawl, Buil-up area, Sustainable development, Environmental degradation

Zusammenfassung

Diese Forschung untersucht die Auswirkungen von Mobilitätssystemen auf die nachhaltige Entwicklung in polyzentrischen Regionen von Entwicklungsländern und konzentriert sich dabei auf die Wechselwirkung zwischen Mobilität und Umwelt-, Wirtschafts- und sozialen Faktoren. Zur Beantwortung der Forschungsfragen und zur Überprüfung der Hypothesen wird die polyzentrische Provinz Mazandaran im Iran als Fallstudie herangezogen, für deren Durchführung eine spezielle Methodik verwendet wurde.

Für jeden Aspekt der nachhaltigen Entwicklung wurden unterschiedliche Indikatoren ausgewählt. Die wirtschaftlichen und sozialen Indikatoren stammen aus öffentlichen statistischen Quellen, während die Indikatoren für die Umwelt und das Mobilitätssystem aufgrund des Mangels an öffentlich verfügbaren Daten entwickelt wurden. Die Zersiedelungstendenzen in der Region wurden analysiert, um die Umweltindikatoren zu berücksichtigen. Dazu gehört die Bewertung der negativen Folgen der Zersiedelung, insbesondere in Bezug auf Flächennutzungsänderungen und Stadtentwicklung, um nützliche Statistiken über die Flächennutzung und Umweltauswirkungen zu sammeln. Darüber hinaus wurde die Entwicklung des Mobilitätsnetzes (in Bezug auf Länge und Fläche) in der Region Mazandaran für die Indikatoren des Mobilitätssystems berücksichtigt.

Quantitative und qualitative Daten zu Umweltindikatoren (Zersiedelung) und Mobilitätsindikatoren (Fläche und Länge des Mobilitätsnetzes) in der Region Mazandaran wurden durch die Analyse von Satellitenfotos von 1995 bis 2020 gewonnen. Um diese Fotos zu interpretieren und die notwendigen statistischen Daten zu extrahieren, wurden Fernerkundungstechniken mit der Plattform Google Earth Engine angewendet.

Die Studie zeigt einen wesentlichen Zusammenhang zwischen der polyzentrischen Struktur und der Entwicklung der bebauten Flächen, der Zersiedelung, der Änderung der Flächennutzung und der Mobilitätsnetze innerhalb der städtischen Gebiete. Diese

wechselseitige Beziehung beschleunigt die Umweltzerstörung in der polyzentrischen Region Mazandaran. Die steigende Zahl der Fahrten zwischen diesen Zentren unterstreicht die Notwendigkeit, die Mobilitätsinfrastruktur auszubauen. Statistische Analysen deuten auf einen starken Zusammenhang zwischen wirtschaftlichen Indikatoren und dem Mobilitätsnetz der Provinz hin, was ein Potenzial für wirtschaftlichen Wohlstand bei verbesserter Mobilität darstellt. Die Provinz ist Zeuge massiver Veränderungen in der Flächennutzung und der Land-Stadt-Wanderung in Verbindung mit dem Ausbau des Verkehrsnetzes und der Erhöhung der beruflichen Möglichkeiten. Während die polyzentrische Raumkonfiguration die Migration erleichtert und zum Beschäftigungswachstum beiträgt, erkennt die Studie die potenzielle Instabilität an und warnt davor, dass die Massenmigration ein langfristiges nachhaltiges Wachstum in wirtschaftlicher und sozialer Hinsicht behindern könnte.

Schlüsselwörter: Polyzentrisch, Mobilität, Zersiedelung, Bebauungsgebiet,
Nachhaltige Entwicklung, Umweltzerstörung

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1. Introduction

1.1 The situation of regional development

Cities host 54% of the world's population, and the coming decades will see significant urbanization and rapid urban development, especially in developing countries (Neiderud, 2015). By 2050, the world's population will be 2.5 billion, with urbanization at 66%. Despite being just 30% in 1950, the city is a complex and dynamic phenomenon that grows physically, socially, economically, politically, and culturally over time(Leeson, 2018). Rapid urbanization due to population growth may result in a scarcity of land for towns, causing sprawl[1] (Esmaeil Poor et al., 2020). Sprawl in urban areas reconfigures cities in developed and developing countries (Oliveira et al., 2020). Sprawl is uncontrolled urban growth in which large and medium-sized cities stretch into low-density, irregular neighborhoods, resulting in different land-use, transportation, and structural patterns. Unplanned development fragments and unstable land-use activities have major environmental effects, including loss of natural capital and the detrimental impact of unplanned commuting on the biological function and structure of the landscape. Loss of rural community identity, demographic division, social homogenization, and economic polarization will also occur (R. Salvia et al., 2018).

[1] There have been several definitions of Urban Sprawl proposed in the literature (Jaeger et al., 2010), but there is no broad agreement on what constitutes sprawl in the urban context (Siedentop, 2005; Wilson et al., 2003). However, the definition of "Sprawl" proposed in this study is: The process of unregulated and illegal construction expansion outside the boundaries of cities with low densities and also, the uncontrolled development of built-up spaces and the land use change of green spaces, forests, protected national and natural parks, high valuable ecological landagricultural lands and the surrounding green spaces of cities for industrial, residential, commercial activities and the development of road networks. This Sprawl process has long-term and short-term environmental, economic and social implications, which some of its dimensions are discussed in different sections of this research.

With its environmental and social repercussions, sprawl contradicts the sustainable development[2] concept and harms social, environmental, and economic growth. Sprawl impairs mobility, accessibility structure and infrastructure too. Most metropolitan districts tried to regulate urban sprawl by building highway networks and improving mobility infrastructure. Some locations implement high-quality public transportation to link the suburbs and metropolises. However, addressing urban sprawl necessitates additional initiatives beyond increased investments in public transportation. Adopting high-quality regional public transit will reduce private car use, trip times, fuel consumption, and greenhouse gas emissions. Long-term urban sprawl or household out-migration to the periphery may restart, increasing urbanization, route length, fuel consumption, emissions, and congestion (Sylvie & Kari, 2007).

Sprawl is sometimes linked to polycentric city-region[3] development. Many cities worldwide seek balance in economic growth and competitiveness, social cohesion, and environmental sustainability; therefore, new spatial arrangements and planning frameworks have emerged (Kwatra et al., 2020). Polycentric development is a spatial planning agenda or vision that has grown in recent years from the urban scale

[2] The 1987 report of the World Commission on Environment and Development, commonly known as the Brundtland Commission, is largely considered as having done much to put the concept "sustainable development" into mainstream consciousness and onto public agendas (Gavrilescu, 2011; Shah, 2008). In this research, sustainable development is defined as "development that satisfies the demands of the present without compromising the ability of future generations to satisfy their own requirements," which is taken from the Brundtland Commission report. Furthermore, sustainable development includes three key components: environmental preservation, economic growth, and social equity, all of which should be given equal weight in every development plan, regardless of its scale.

[3] According to Kloosterman & Lambregts (Kloosterman & Lambregts, 2001), Polycentric urban regions, also known as urban networks, are often associated with synergy and collaboration. The idea is that the whole network of cities is greater than the sum of its parts because of the synergistic interactions of its constituent parts. Additionally, the polycentric urban area has a comprehensive description and categorization. Nonetheless, the notion of the Polycentric City-Region will be discussed in subsequent chapters; its definition in this study stated as follows: These polycentric urban regions can be defined as follows: (1) They consist of several historically separate cities situated nearby (roughly within one-hour commuting distances). (2) They do not have an obvious leading city that dominates in political, economic, cultural, and other areas. Rather, they consist of a smaller number of major cities comparable in size and economic significance and a larger number of smaller cities. (3) Not only are the member cities geographically unique, but they are also political entities.

(Asprogerakas & Zachari, 2020) to regional entities and then to the national level. Global cities are becoming more polycentric, say researchers. This has led to extensive theoretical and political literature on "decentralization" in the last two decades, focusing on "polycentric urban region." Rhine-Ruhr area in Germany (Dühr, 2021) and many other instances in Europe and Asia used a polycentric framework for spatial organization.

In less developed societies without an efficient city planning and management system, the complexity of relationships in polycentric city-regions, mismanagement of methods and ways to deal with such complexities, and continuity of problems eliminate vital economic, social, physical, and environmental resources as sustainable development elements. Traditional methods and practices cannot handle polycentric city-regions. If this continues, city-region spatial systems will be abandoned, and difficulties will mount.

The situation of polycentric city-regions, uncontrolled sprawl within their boundaries, mobility, massive land use change, environmental degradation and loss of biodiversity, and transportation infrastructure that stems from the necessity of guiding and controlling it confront polycentric city-regions with various challenges and barriers to achieving sustainable development goals at the regional scale. These challenges can be named but are not limited as follows:

- Challenges related to the management and development control of the polycentric city-regions.
- Challenges regarding the Spatial configuration of the polycentric city-regions
- Challenges concerning mobility, transportation, and commuting management.
- Challenges regarding sprawl management and control,
- Environmental challenges and ecologically valuable land degradation and sustainable regional development

Despite these problems, the polycentric city-region has always struggled with mobility. Creating a single transportation policy in polycentric city-regions has been challenging. Development activities and strategies have traditionally emphasized mobility, and regarding the necessity of sustainability issues, "sustainable mobility" became a policy priority after the early 1990s united nations sustainable development summit (Gudmundsson et al., 2016). Mobility in polycentric city-regions is twofold. First, as an accessibility issue for peripheral areas, and second, as an efficiency issue for central areas. Accessibility improvements are important in developing polycentric city-regions and a precondition for allowing settlement centers to pursue economic development within a spatial harmonization strategy. Cities as nodes in a polycentric development paradigm are similar and must be connected to local and global economic networks (Herrschel, 2009). Mobility and telecommunications are needed to improve the competitiveness of peripheral and underserved regions and the social and economic cohesion of polycentric city-regions. Thus, mobility is key to polycentric development (Richardson & Jensen, 2000).

Further, spatial inequities in polycentric city-region cannot be reduced without better transportation infrastructure and services to and within regions with limited access (Harrison, 2010). Expanding regional transportation infrastructure like highways may lead to regional sprawl, consuming natural resources like land. Polycentric city-regions will expand this situation. Sprawl has several negative effects on sustainable development, especially on the regional scale (Kaumars Irandoost et al., 2018).

1.2 Describing the subject of the research

Rapid population growth and urban expansion pose issues including sprawl, land consumption, the need to develop more mobility infrastructure, confronting sustainable development goals and forming distinctive spatial structures like polycentric spatial arrangement. Developing countries face additional complexity in coping with the undesirable implications of these difficulties due to their dynamic

character. The Mazandaran province of Iran will be employed as a case study to attain a pragmatic comprehension of a developing nation.

The polycentric structure of the Mazandaran city-region results from environmental factors and limitations, especially its location in the corridor between the Caspian Sea and the Alborz-mountain range, fertile land and suitable ecological zone. It is impossible to form significant metropolises in this province because it is difficult to pass through or has limited access to different parts. However, because of the province's unique polycentric spatial structure, it is integrated with complex and interconnected functional relationships. Thus, traditional approaches to development planning, sprawl control and management, transportation, mobility planning and operation do not meet the real needs of this polycentric city-region.

These approaches will worsen the province's issues by seeing housing centers and their activities as separate elements and a lack of integrity in the province's administration and planning. Furthermore, the Mazandaran polycentric city-region is now facing several environmental and economic issues and physical growth in the form of sprawl and informal economic activity on the outskirts of urban centers, demonstrating a conflict between the unique features of this city-region and the techniques of development management and control.

Due to its position in northern Iran and closeness to its capital, Tehran, Mazandaran serves as a hub for linking Tehran to other metropolitan centers in eastern Iran, such as Mashhad and Gorgan (Haqjou, 2015). In addition, despite its lack of tourism and transportation facilities, Mazandaran attracts tourists, commuters, and visitors from other areas of the nation and serves around 15 million visitors annually. At the same time, it has a population of roughly 3 million people. Furthermore, directly and indirectly, unanticipated mobility demand caused by uncontrolled urban development, land-use changes, and sprawl, as well as decision-making challenges, places enormous tension on this polycentric city-region and, on a broader scale, impedes sustainable development progress in this region. The previously outlined problems in polycentric

city-regions were made worse by the following factors (Mazandtarh Consulting Engineers, 2010c):

- Inattention to the region's polycentric nature in land-development and transportation planning
- Inefficient regional and local mobility system
- Lack of integration and consideration of the critical role and preservation of the Ecological, green area, green boundary of cities and agricultural land in mobility plans and land development plans on local and regional scale

In any event, polycentric city-regions within nations are part of a larger spatial system. They should interact with other areas with various spatial structures, such as monocentric zones with unique development requirements. The Mazandaran polycentric city-region, one of Iran's 32 provinces, is situated in the country's north and deals with spatial interaction with other areas and provinces. However, as a developing country with diverse geographical and spatial patterns, Iran has several spatial concerns, including urban environmental issues, inefficient public transit, and local, regional, and national mobility. Furthermore, on a big scale, Iran confronted the challenge of urban sprawl and substantial land-use change in key ecological and agricultural areas.

Given the nature of the challenges that have already been discussed about the polycentric city-regions, it requires a satisfactory answer to improve the existing conditions of sprawl, development process, environment and ecological zone preservation and mobility system, which this study focuses on Mazandaran province as a case study as part of a larger spatial system in a developing country like Iran and seeks to explain them through employing techniques and methods as well as successful polycentric city-region experiences.

1.3 Research Objectives, Questions, and Hypothesis

1.3.1 Importance and necessity of research

The polycentric urban design promotes social cohesion, economic competitiveness, and environmental sustainability (Veneri & Burgalassi, 2012). According to the ESDP[4] (ESDP, 1999), sustainable development requires polycentric development. More recently, 'An agenda for a reformed cohesion policy,' a guide paper for the EU's[5] new cohesion policies, stressed the relevance of networked polycentric regions in supporting balanced territorial development and addressing the drawbacks of major metropolitan agglomerations (Barca, 2009). Polycentric urban expansion has diverse and nuanced effects on SDGs, although many analysts regard it as largely positive (Coenen et al., 2021; Kumar et al., 2022).

The significance of this research lies in its exploration of the relationship between polycentric urban forms, sustainable development, and mobility infrastructure. Scholars (Papa & Bertolini, 2015; Zhao et al., 2010) have noted that polycentric transportation can reduce private automobile movements and emissions while enhancing land use combinations and minimizing commute distances. This urban form also promotes public transit, which reduces carbon emissions and preserves open spaces while mitigating urban heat island effects (Park et al., 2020a; Wei & Ewing, 2018). Moreover, adopting a polycentric structure has been associated with economic success and mitigating negative agglomeration diseconomies (Fujita & Ogawa, 1982; Meijers & Burger, 2009). However, there is a limitation in existing theoretical and empirical studies, particularly in the context of developing countries like Iran. The lack of clear definitions, assessment tools for sprawl, and understanding the relationship between sprawl and mobility network development hinder the potential of polycentric

[4] European Spatial Development Perspective
[5] European Union

development in different regions. Addressing these gaps is crucial for properly treating and recognizing the polycentric development potential in developing countries.

Furthermore, the conceptual issues concerning polycentric urban areas in developing countries lead the term to be employed freely with varied sizes and viewpoints. As a result, it will result in inaccuracy and loss of meaning, which can have various consequences. Therefore, the advantages of this development, as well as the development of the accessibility and mobility network, stay hidden. Other requirements related to the development of an accessible network, polycentric urban development and its relationship with sprawl, and sustainable development might be posed in this regard as follows:

- The requirements for a regional approach to urbanization and development
- The requirements to increase organizational capability in the city and region
- The requirements for a precise definition of polycentric city-region
- The requirements of considering the mobility system's crucial role in sustainable development
- The requirements of considering sprawl's crucial role in sustainable development

1.3.2 Research goals

The general objectives of the dissertation are formed in response to the general questions. These objectives can be classified into two categories:

- Objective 1: Clarifying the concept of polycentric urban areas as an analytical and planning tool.
- Objective 2: Identifying unsustainable physical and environmental development tendencies in the polycentric city-region.

However, the dissertation's objectives are linked to the goals of the inquiry. In addition, the objectives established in this regard attempt to address why and how to use this notion in the case study (Mazandaran region) and on a bigger scale in Iran.

- Objective 1: Identifying the relationship between mobility network development and sustainable regional development, notably in the Mazandaran region.
- Objective 2: Research the disciplines and areas of planning for applying Polycentric City-Region planning, develop the mobility network and improve sustainable development indicators in Mazandaran province.
- Objective 3: To provide planning data for application in polycentric urban development, sprawl control, and rational development of mobility networks in the case study.

1.3.3 Research questions and hypothesis

Main question: Is the structure of the polycentric city-region mobility system having an impact on sustainable regional development?

- Question 1: Does the polycentric mobility system's structure impact the dimension of the natural environment sustainability of the area's sustainable development?
- Hypothesis 1: It appears that the structure of the polycentric city-region mobility system influences excessive natural resource usage.
- Research variables: Built-up area; The amount of valuable ecological, agricultural, green space, green boundaries of cities, and preserved national parks and land consumption due to sprawl.

- Question 2: Does the configuration of the mobility system influence the economic efficiency factor of sustainable regional development?
- Hypothesis 2: The nature of the polycentric city-region mobility system appears to have rendered economic linkages ineffective.
- Research variables: Growth of commodities displaced and growth of (parcels) postal shipping.

- Question 3: Is the framework of the polycentric city-region mobility system affecting the social structure and dimension of Mazandaran's sustainable regional development?
- Hypothesis 3: The structure of the polycentric city-region mobility system appears to have an impact on all social constructs.
- Research variable: Employment growth and urban population growth

1.4 Introducing the method and process of research

1.4.1 Research Process

This research's main method is hypothetical-deductive, based on the six-step scientific method and "hypothetical-inductive." Hypothetical-inductive and hypothetical-deductive are essential scientific approaches. The hypothetical-deductive method drives the goal-setting process. In the hypothetical-deductive method, the model's building begins with a default interpretation of the study subject. This model makes assumptions, concepts, and indications that logic must confirm or reject. Also, a "case study" or "single case study" is a supplementary approach for evaluating hypotheses based on the hypothetical-deductive scientific method because the events under examination cannot be controlled. All hypothetical-deductive operations in this dissertation have six steps as follows:

- Step one: Discovering the research questions.

The study's primary purpose is to explain the phenomenon of polycentric urban development in the country's cities and regional complexes. The answer to this question creates other theoretical issues: What are a polycentric urban area's definition and concept? What are the opinions on the subject? What are the concept's dimensions and criteria? Where do these areas stand in terms of spatial development?

- Step Two: Exploratory Studies

Existing theories concerning polycentric urban environments and international experiences in this field are now being researched. The subject's theoretical structures are investigated to extract essential ideas and identify the subject's fundamental assumptions. Finally, pay close attention to the essential assumptions and concepts behind the original inquiry. The approaches that have been taken to the topic, as well as the hypotheses underlying these theories, may inspire additional work and highlight the next stage, which is constructing the theoretical framework and analysis model for the research, which in this case is analyzing the impact of the mobility system in a polycentric system and the consequences of sprawl in such a structure.

- Step Three: Theoretical design of the research problem

Depending on the process, one may identify or build a perspective or view that best answers the original inquiry after assessing all explored concepts. This perspective, which acts as the research's theoretical framework, is achieved by modifying and evaluating the chosen theories and using them to accomplish the research's theoretical framework. A conceptual model and a framework for research analysis will be developed using the theoretical framework.

- Step Four: Build the analysis model.

This model attempts to transform the theoretical framework's principles into an experimental and observable language to acquire information about them. At this

phase, the hypotheses investigated in the analytical model have replaced the original inquiries.

- Step Five: View

The analysis model will be used as an intermediary or hinge to connect the theoretical design and model concepts at this stage. It will also be utilized to test ideas using empirical or statistical data and documentary observation.

- Step Six: Data Processing and Information Analysis

Proper tools and techniques are required to process data within the study framework and analysis model. The techniques and tools used in this research are discussed in depth in other chapters. Consequently, this section only mentions a few research approaches and tools:

- Arc-GIS analysis
- Google spatial analysis tools
- Satellite images analysis
- Statistics analysis

1.4.2 The expected results of the research

Based on the theoretical foundations as well as global experiences in dealing with and managing polycentric city-regions, which is the main subject of this research, as well as the special efforts that have been made so far regarding the spatial structure of the city-region of Mazandaran and its challenges, the following are the expected results of this study:

Tracing and providing theoretical, technological, and experimental frameworks associated with polycentric city-regions and effective approaches for dealing with these regions' unique issues, such as mobility planning, development planning, and control, and also describing and analyzing the theoretical, technical, and experimental framework related to the negative consequences of excessive valuable land

consumption to development activity, such as road development and housing development, on ecological and natural resources such as agricultural land and green areas. In addition, the effects of public transportation vs. individual mobility, unplanned mobility, and transportation network development in a polycentric city-region are discussed. It also examines these adverse consequences on the sustainable development process on a regional scale.

1.4.3 Methodology of the Research

This part focuses on the design of the research and the creation of the associated methodology, which includes acquiring and producing data as well as related equipment and software for processing and analyzing data to provide answers to research questions. This is done as part of validating the research assumptions and answering the questions provided by the study. As a result of this project, the transportation system in the Mazandaran polycentric city-region will be studied in terms of the environmental, economic, and social factors through respective indicators chosen for each element concerning data availability on a scale appropriate for the area.

Regarding environmental indicators, the mobility system has several associated indicators and variables, including noise, land-use change derived from land consumed for developing mobility infrastructure (accessibility network), and related air pollution from commuting vehicles. However, sprawl was the most closely related indicator to the concept of mobility for this research regarding limitation in data availability concerning the region's mobility system. Indeed, by analyzing the sprawl of a region, the amount of consumed land for different activities, including consumed land for developing roads and other mobility system infrastructure, can be calculated. Also, it allows for examining the association between the development of the mobility system infrastructure and other development activities. Besides, due to data availability limitations in the Mazandaran area for the mobility system, the researcher decided to calculate the length of the Mazandaran region's mobility network as an indicator using an innovative satellite image method.

Further, to assess the impact of the mobility system on Mazandaran's sustainable development process, as previously discussed, the sprawl indicator in the region was chosen as an environmental indicator owing to data availability constraints. However, estimating built-up areas is critical for studying sprawl and its effects on the rapidly changing planet (Roy Chowdhury et al., 2018). However, due to insufficient data concerning Mazandaran's built-up area in related public resources, this data had to be

calculated using satellite images. Because remote sensing is the most applicable method for interpreting satellite images (Dhaoui, 2018), it was used to calculate the built-up area for Mazandaran boundaries. Remote sensing is the science of interpreting objects based on measurements taken from a distance without coming into physical contact with the objects under study. The remote sensing system is a powerful tool for researching urban issues such as land cover change, urban growth modeling, urban sprawl, and so on. However, software or a cloud-based analyzer is required to use remote sensing. In this regard, the most widely available tool, Google-Earth Engine, was chosen to carry out the remote sensing analysis. This chapter will then outline the statistics model used for representations of variable analysis and, finally, will represent the conceptual framework of the interaction of Mazandaran polycentric city-region's mobility and sustainable development.

- Remote sensing analysis

The FAO-GAUL[6] provided the official administrative boundary of Mazandaran province, which was used in the project's first step. It is important to remember that this study's geospatial and statistical analyses are all based on openly available data. FAO-GAUL organizes and distributes the best available data on official units from all countries to ensure a consistent spatial representation of administrative units. A country-by-country breakdown of the available data is provided country-by-country (FAO, 2015). The FAO-GAUL administrative county-level shapefile can make regional and local data on urban sprawl available (FAO, 2015). As a result, data on urban sprawl could be made available at the regional and local levels using the FAO-GAUL administrative county-level shape-file.

An analyzer platform called Google-Earth Engine, which uses Google's massive computing power in the form of Google's cloud computing platform has been used for large-scale geospatial analysis, such as deforestation, disaster, and environmental

[6] The Food and Agriculture Organization of the United Nations Global Administrative Unit Layers

protection. Remote sensing experts and individuals without a scientific background can benefit from this distinctive platform, specifically engineered to interface seamlessly with traditional supercomputers and extensive cloud computing resources dedicated to large-scale data processing. In addition to satellite and aerial imagery, the Google-Earth Engine hosts a variety of other publicly available geospatial datasets. For geospatial analysis, it can also import external satellite images (Gorelick et al., 2017).

- Satellite Images & Built-up area calculation

This study relied on Landsat 7 and Copernicus global land service satellite images of Mazandaran. As a first step, all available Landsat 7 satellite imagery was retrieved for the Mazandaran region from 2000 to 2020, with a 30-meter nominal resolution and 16-day temporal granularity, considering availability (based on the administrative boundary). Scaled, calibrated at-sensor radiance satellite images are provided by Landsat 7. It is thought that Tier-1 Landsat satellites have the best data quality and are suitable for time series processing analysis. All Landsat sensors are intercalibrated in Tier-1, which includes Level-1 Precision Terrain (L1TP) data. No matter what type of sensor is used, all Tier-1 Landsat data can be recognized and inter-calibrated (USGS, 2011).

All available Copernicus global land cover Layers, CGLS-LC100 collection three images were called and then cropped to fit and cover Mazandaran administration boundaries. Noteworthy is that the Copernicus global land service (CGLS) is designated as a part of the Land service to provide bio-geophysical outcomes on the state and evolution of Earth's land surfaces. The dynamic land cover map provides land cover data at 100 m resolution with 100-meter resolution (CGLS-LC100). The output of each land cover type includes a set of continuous field layers that estimate vegetation/ground cover. This ongoing classification project may better depict areas with different land cover types than the standard classification system and, as such, can be tailored for application use (e.g., forest monitoring, crop monitoring, and so on.). Land cover maps (v3.0.1) derived from the PROBA-V 100-meter time series, a

database of high-quality land cover preparation sites, and various ancillary datasets are included in Copernicus satellite images for the entire globe from 2015 to 2019, with an accuracy of 80% at Level-1 over the years (Buchhorn et al., 2020). In the next phase, all the clouds, noises and air pollution have been removed and combined.

- Noise reduction and removing air pollution and clouds.

In satellite image classification, dealing with noise is one of the most difficult aspects to overcome. Satellite images may be riddled with noise. The images contain noise from various sources, including atmospheric effects, thermal noise, sensor degradation, and signal processing. For example, noise can get into classification, affecting the model's performance and output state. Because a large portion of a pixel's signal could come from nearby pixels, pixel-based classifications were particularly vulnerable to noise. There are a variety of ways to lessen the impact of noise. Images can be pre-processed or post-processed using these techniques (Khanal et al., 2020).

To understand statistics in an image region by compositing images from different temporal spans, it is necessary to reduce "Spatial reduction" refers to this phenomenon. Reducing a collection of images to an individual image is a temporal reduction. Reducing overlapping pixels can be done by using the reducer type. Landsat-7 returns to the same spot on the earth every 16 days. Approximately 12 images are implied, possibly more where the points of view intersect. A high-resolution, one-of-a-kind satellite map with a high statistical value is what reducing provides. The absence of clouds and shadows enhances the quality of the image. To reduce an image set, the median reducer takes the average of each band's time values and combines them to produce a composite value.

- Calculated normalized built-up area index (NDBI)

The Normalized Built-up Area Index (NDBI) estimates the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) (Vinh et al., 2020). Landsat data is commonly used for classification. Landsat-7 has eight data bands on its wavelength (blue band, green band, red band, infrared band, thermal band, panchromatic). Only four bands (Green, Red, NIR, SWIR) are used for the normal difference built-up index (NDBI) analysis (Alexander, 2020). In this analysis step, the NDBI is calculated using the below formula in the earth engine after estimating built-up urban areas.

$$\boldsymbol{NDBI} = \frac{(\text{SWIR} - \text{NIR})}{(\text{SWIR} + \text{NIR})}$$

And for Landsat 7, the formula is as follows:

$$\boldsymbol{NDBI} = \frac{(\text{Band 5} - \text{Band 4})}{(\text{Band 5} + \text{Band 4})}$$

Furthermore, the NDBI value ranges from -1 to +1. The negative value of NDBI represents water bodies, while the positive value represents built-up areas. The vegetation NDBI value is low (Paul & Pal, 2020). Finally, after applying a threshold, the respective algorithm calculates the pixels representing urban areas, resulting in quantitative and statistical data about urban built-up areas.

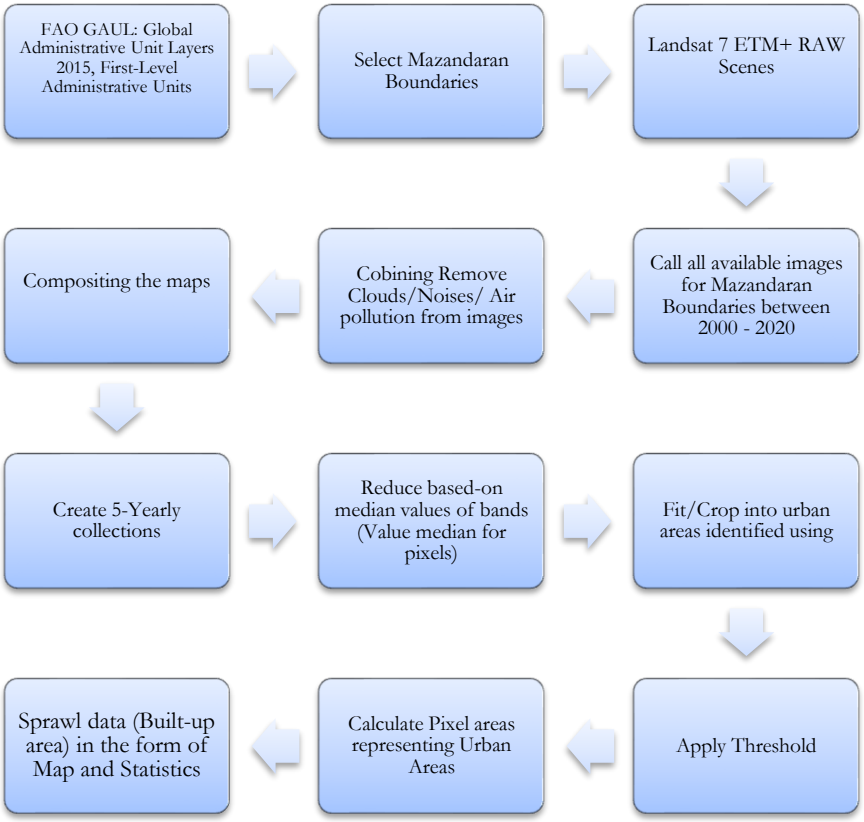


Figure 1 Framework of the sprawl data calculation from Landsat-7 satellite source in Google-Earth Engine area.

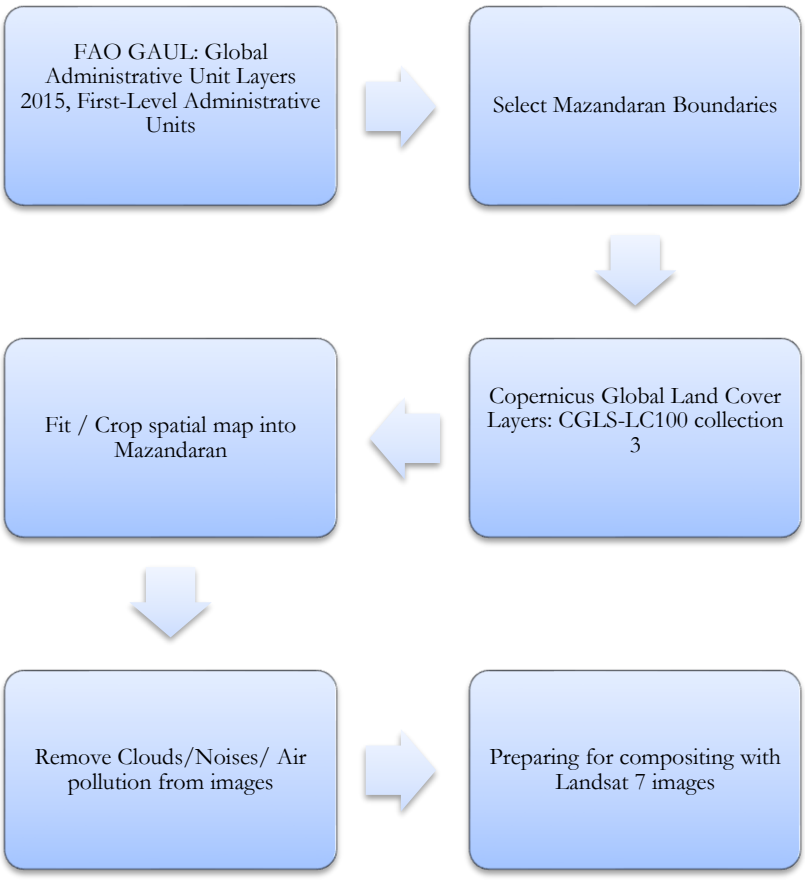


Figure 2 Framework of the sprawl data calculation from Copernicus satellite images in the Google-Earth Engine area

- Mobility network

To overcome Google-Earth engine obstacles to accurate road recognition and accessibility from satellite images, as well as a lack of publicly available data in these categories, OSM[7] resources were used. OSM is a collaborative project that aims to create a free, editable map of the entire world. The geodata underlying the map is regarded as the project's primary output. For the study's time span (1990-2020), three sets of mobility data were available: primary, secondary, and tertiary roads. Primary and secondary roads are classified as regional roads and interconnect the counties for the region, while tertiary roads are classified as local and internal county accessibility.

[7] Open Street Map

Because this research focuses on the regional scale, the first two sets of data, primary and secondary roads, were considered. QGIS software 3.18.1-Zürich version and OSM downloader plugin version 1.0.3 were used to extract the OSM accessibility shape file within Mazandaran province FAO-GUAL administration boundaries. Data obtained from the OSM repositories for Mazandaran included shape files with varying levels of accessibility in the form of maps and statistical data. Any mobility system would be incomplete without a well-developed road and accessibility network. Regrettably, only a portion of Mazandaran's accessibility and road network has been studied in planning and scientific documents available in public databases. However, there appears to be a lack of publicly available data. Here, the researcher attempted to generate the necessary data to answer the research question creatively. In the Methodology chapter, the author explained that OSM maps access data is the primary foundation for combining satellite maps using Google-Earth Engine and Google-Earth. As a result, the length and area of Mazandaran's primary and secondary mobility networks at the county level have been determined.

- Economic and social variable

Statistical data from various categories is essential to deal with the economic and social aspects of the Mazandaran province's long-term development. While the Iranian national statistics organization publishes statistics reports yearly, due to the fragmented structure of governmental bodies responsible for statistics, concrete statistical data of related variables for sustainable development in Iran is not sufficiently and publicly available. This study uses required statistic data from various available resources, including public data from the road and urban development ministry, which has been cited in this study. Regarding data availability, social indicators such as the number of employed people and the urban population variable were chosen, and for economic aspects, the growth of freight and the growth of (parcels) postal shipping were considered.

- Statistics analysis

Finally, statistical analysis with appropriate methods will be performed to answer the research questions by analyzing raw available and produced data. There are various computational methods for measuring the dependence or relationship between two random variables in statistical multivariate analysis. The correlation coefficient between two variables represents the ability to predict the value of one variable in relation to another. Supply and demand, for example, are two interdependent phenomena. Calculating the "covariance" or "correlation coefficient" between two variables is one way to demonstrate their relationship.

The correlation between two variables only indicates the effect of one variable's increase or decrease on the increase or decrease of the other variable; however, it does not imply a causal relationship between the variables. As a result, a distinction must be made between the concepts of solidarity and cause-and-effect. In other words, two variables can be correlated, but one does not have to be the cause and the other the effect; additionally, several other factors can influence the correlation coefficient. The stronger the relationship or dependence between the two variables, the higher the value of these indicators.

- Pearson correlation coefficient

There are several correlation coefficient models, but the appropriate correlation coefficient should be used depending on the nature of the analysis data. Regarding the quantitative (distance-relative) nature of the available data in this study, the Pearson correlation coefficient has been used with the following assumptions concerning the data used in this study:

- The scale of the variables is at least a distance.
- Distributions are almost normal.
- The relationship between the two variables is linear.
- The same condition of variances must be observed.

It should be noted that the Pearson coefficient is a spatial cross-correlation (Chen, 2015), and it is used to measure the relationship between two types of variables in urban and regional studies with quantitative data, which aids in understanding their relationship and the effects that each will have on the other. Concerning the preceding, the Pearson correlation coefficient, also known as Pearson torque correlation coefficient, correlation coefficient, and bilateral correlation coefficient, is used to calculate the degree and amount of linear relationship between two variables. The correlation coefficients range from -1 to +1. A coefficient closer to +1 indicates a strong and positive relationship between the two variables. In other words, as each of the other variables increases, it decreases, and vice versa; as each of the other variables decreases, it decreases. In other words, as one variable increases, the other decreases, and as one variable increases, the other increases. The Pearson correlation coefficient calculates the correlation between two distance or relative variables (Schober & Schwarte, 2018). It should be noted; however, that covariance or correlation does not indicate a cause-and-effect relationship but is a measure of the degree of dependence between two variables. Pearson coefficient abbreviation is (r), which shows the degree to which quantitative variables have a linear relationship.

$$r = \frac{\sum(x_{i-}\,\overline{x}\,)\sum(y_{i-}\,\overline{y}\,)}{\sqrt{\sum(x_{i-}\,\overline{x}\,)^{\,2}\sum(y_{i-}\,\overline{y}\,)^{\,2}}}$$

r =correlation coefficient

x_i=values of the x-variable in a sample

$\overline{x}$ =mean of the values of the x-variable

y_i =values of the y-variable in a sample

$\overline{y}$ =mean of the values of the y-variable

The assessment of the relationship's intensity should follow the determination of its significance and direction. Various categorizations are proposed for interpreting the strength of the relationship between two variables, and one such categorization is delineated as follows in Table 1.

Intensity of relationship	**Interpretation**
0.8 – 1	Very strong relationship
0.6 – 0.8	Strong Relationship
0.4 – 0.6	Medium relationship
0.2 – 0.4	Low (or weak) relationship
0.0 – 0.2	Lack of relationship or insignificant relationship

Table 1 Interpretation table of relationship intensity in Pearson correlation

- Conceptual framework of the research

This study employs many indicators (Figure 3) to assess the impact of the region's mobility system on the Mazandaran polycentric city-region's sustainable development process. It is worth noting that the indications concerning data availability have been chosen. In addition to analyzing the influence and relationship of the indicators in this study, the author developed the conceptual model presented in figure four.

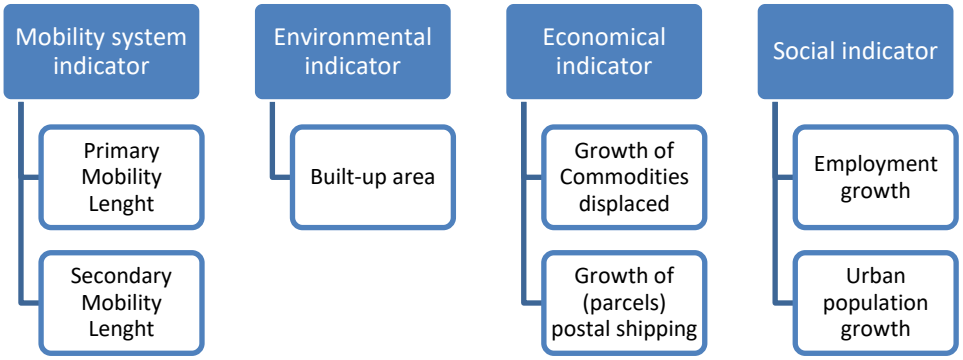


Figure 3. Targeted research indicators

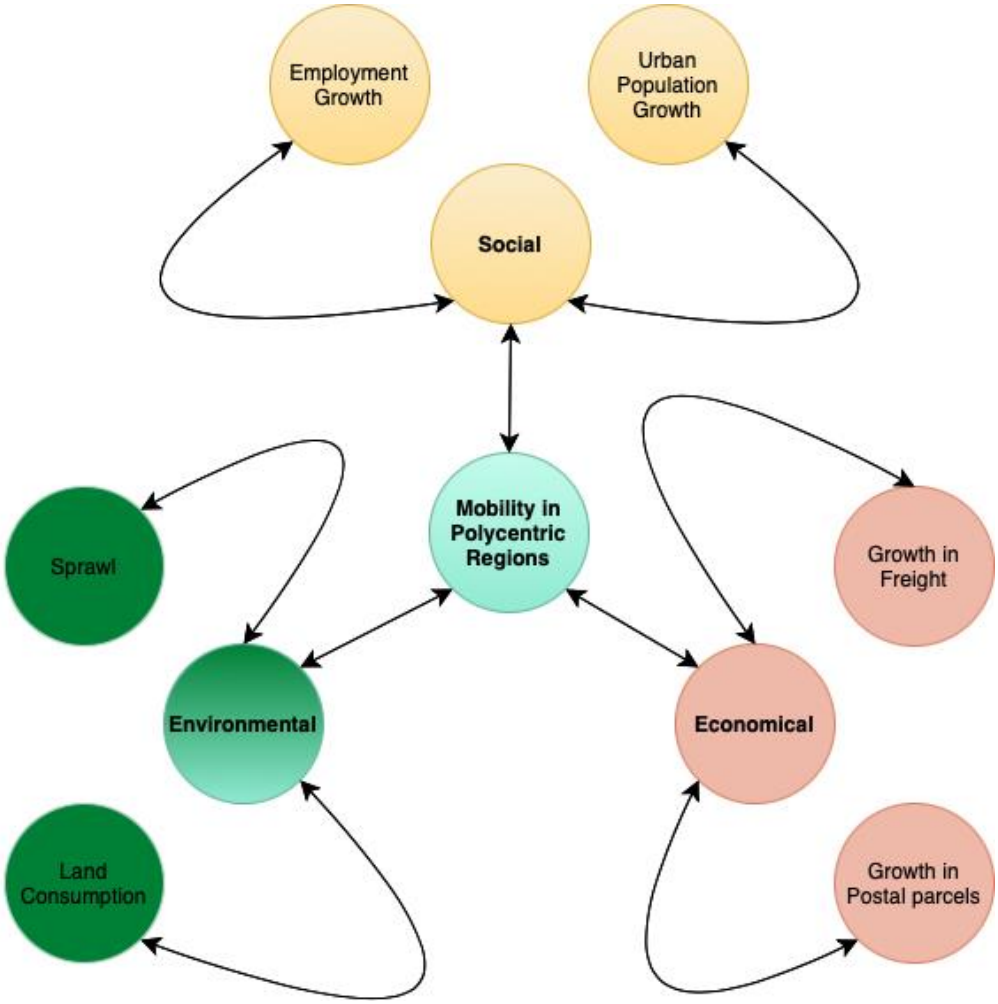


Figure 4 Conceptual research framework and elements interactions of mobility and sustainable development in Mazandaran region (Source: The author).

2. Problems and Challenges of Sustainable Development

2.1 Sustainability and Regional challenges

2.1.1 Sustainability and Development at Regional Scale

Rapid globalization over the decades has led to a dramatic rise in the use of natural resources and the destruction of ecological systems (Gills, 2020). In this regard, the importance of sustainable development has been emphasized more recently after the 1987 report of the world commission on environment and development, commonly known as the Brundtland-Commission[8], which defined sustainable development as "development that satisfies the demands of the present without compromising the ability of future generations to satisfy their requirements," is largely considered as having done much to put the concept "sustainable development" into mainstream consciousness and onto public agendas (Gavrilescu, 2011; Shah, 2008). Concerning this definition, Sustainable development has three pillars (Figure 5): society, environment, and economy.

[8] In 1987, the World Commission on Environment and Development (WCED) released "Our Common Future." Gro Harlem Brundtland, the Commission's chairwoman, gave the report her name. It developed sustainable development's guiding principles. According to the Brundtland Report, global environmental challenges are caused by poverty in the South and unsustainable consumption and production in the North. In1989, the UN General Assembly considered the report and decided to host a UN Conference on Environment and Development.

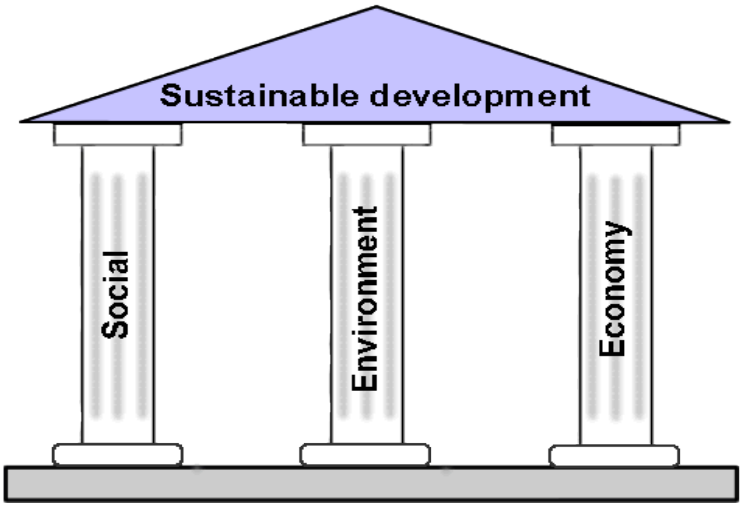


Figure 5 Three pillars of sustainability (Resource: Author)

Sustainable development is progress that helps the present generation and those who will live in the future (Gills, 2020; Holmberg & Sandbrook, 2019; A. L. Salvia et al., 2019). Human contexts are considered alongside ecological and environmental factors. The notion of sustainability serves as the guiding principle for the foundation of the many actions that make up sustainable development (Broman & Robèrt, 2017).

The term "sustainability" is used to describe a system's ability to continue operating indefinitely without any changes to its status, usefulness, or present facilities, as well as without any changes to the resources the system uses to carry out its activities (Shams Alsadat Zahedi, 2011). This mode of growth involves constant evaluation and adjustment, considering sustainability principles to ensure that the best decisions are taken for the benefit of society as a whole and for the preservation of its resources (Solow, 2014).

Sustainable development is based on economic-environmental integration, environmental protection, intragenerational justice, quality of life, and participation of society members in the development process (Prizzia, 2017), and it becomes objective when it first improves the quality of human life and then saves the planet's live ability (Shams Alsadat Zahedi, 2011).

Concerning the protection of the planet's ability to live, it is considered a development based on which life support systems and ecological processes that cause the continuation of the cycle of basic elements including but not limited to air, water, soil and natural elements (Zinina & Olentsova, 2020) and also preserve the diversity of biological species be; the sustainability of renewable resources is guaranteed; the consumption of non-renewable resources should be minimized, and the carrying capacity of the land and ecosystem should be obsessively monitored (Naeem et al., 2016). Sustainable development may be defined as stewarding the interdependence of human systems and natural ecosystems so that both present and future generations benefit from responsible resource management (Shah, 2008). In sustainable development planning, concerns regarding the consequences of a system on other sections are explored, as well as the fundamental issue of whether the interaction of existing systems leads to improved efficiency and effectiveness (Shams Alsadat Zahedi, 2011).

2.1.2 Sustainable regional development

In recent decades, the argument over regional development has changed significantly. There is a strong link between the debate over regional development and the debate over sustainable development. There is much optimism that regional development policies will lead to long-term growth (Schleicher-Tappeser et al., 1997a). When the phrases "Regional" and "Sustainable" are compared, it is clear that they cannot be treated at the same level. A space is defined by "Regional," but a quality is defined by "Sustainable." The notion of sustainability necessitates a massive paradigm shift, which has been ongoing for decades in search of a new way of seeing the evolution of human communities on our planet. The earlier value systems do not seem cohesive from the new viewpoint (Rezvan Abbasi, 2015).

Regional development, on the other hand, is not a standalone idea. Several theories can be used to explain and comprehend the regional economic development of societies (Song et al., 2019). In this discipline, normative assumptions and action-

oriented theories exist that state what should be done. Academic policies at the national and regional levels also assist regional growth. Regional development addresses regional concerns (Rezvan Abbasi, 2015). While economic concentration dominates regional development, other factors, such as environmental and social development, are becoming more important (Pike et al., 2018).

As a result, the premise of sustainable development has a wide claim in terms of its theme (people and the environment), scale (from individual to global), and moral conceptions (survival conditions) (Rezvan Abbasi, 2015). On the other hand, regional development is more interconnected due to its focus on the regional level. This assumption's long history, as well as its smaller scope, has resulted in experience with applicable models and tactics. The comparison between sustainable development with regional development demonstrates that regional development is a response to geographical issues, while sustainable development emphasizes temporal elements (Schleicher-Tappeser et al., 1997b).

Regional development should maximize component ratios (social, environmental, and economic components of regional development), conventional policies in an area and socioeconomic processes in specific political and cultural situations (Tamošiūnas, 2009). Today, however, the term "sustainability" is used to represent a variety of mindsets, development methods, and planning methodologies. Integrating local needs and requirements into central policies, plans, and objectives is essential for regional sustainability (Pike et al., 2018).

However, the concept of sustainable regional development refers to the incorporation of sustainable development concepts in the implementation of regional development. As a result, regional sustainable development encompasses all of the actions and instruments that sustainable development produces in the economic initiative (Rezvan Abbasi, 2015). This emphasis is recognized first by the importance of regions as intermediates between the national and local levels and second by the emerging

understanding that sustainability is a crucial criterion in future regional development (Clement et al., 2003).

Regional development may become the most crucial launching pad for strengthening sustainability in the future. The regional component is appropriate for redefining the concept of sustainable social, economic, and environmental systems in a practical and close-to-people manner, as well as for making practical public choices (Pike et al., 2018; Rezvan Abbasi, 2015; Schleicher-Tappeser et al., 1997b).

2.1.3 Dimensions of sustainable development at the regional level

- The relationship between environmental and economic dimensions

The economy is an open system in science; it takes natural resources from the environment and returns pollution and waste to it. Economic growth requires natural resource exploitation and environmental pollution. If we are not careful, it might cause its extinction (Rezvan Abbasi, 2015). Environmental protection involves diverting scarce economic resources to the environment. The environment is used as a production input in the economy; hence, there are cooperative consequences. Improving environmental quality improves industrial process efficiency and economic efficiency (Panayotou, 2016). For instance, reducing air pollution decreases the cost of air purification; improving water quality in rivers, lakes, and seas improves fishing output; and reducing soil contamination improves agricultural efficiency.

In contrast to the scenario where nature is exploited, environmental conservation often means a short-term decrease in economic development. It defines a competitive interaction between economic and environmental capital, particularly relevant in the short term (Ahlheim, 2009). In the long run, the outlook is different: ignoring environmental protection today leads to lower economic growth in the future because economic growth is dependent on a healthy environment; on the other hand, optional environmental protection is realistic only in a society that has already achieved a certain level of economic well-being. This fact refers to the link between economic and

environmental development. In the sense that these two components of sustainability compete in the short term while complementing each other in the long run (Ahlheim, 2009).

- The relationship between economic and social dimensions

Social sustainability is often considered social stability. Social sustainability requires a minimum level of living satisfaction for all citizens in the present and future and a balance between different social groups (Rezvan Abbasi, 2015). Long-term social sustainability demonstrates that society must provide people with a future. It requires the stability of society's economic system so people can plan their future. Establishing incentives to encourage individuals to pursue education and make investments in their later years is of paramount importance (Magis, 2010). Such incentives can only be generated if people are certain that social instability or political revolutions will not affect their human and financial capital. Political and economic stability is essential for national and regional social stability (Rezvan Abbasi, 2015). Social sustainability involves allocating money and wealth based on people's perceptions of equity and justice (Syme et al., 1999). In this respect, when the fulfillment of several obligations about economic well-being and social justice comes largely within the scope of the central government, the collaboration of regional governments is essential(Ahlheim, 2009; Rezvan Abbasi, 2015).

Furthermore, social welfare is typically related to potential economic growth obstacles, as redistributing income and wealth can dissuade economically successful people from participating (Midgley, 1999). Rapid economic expansion leads to uneven wealth and income distribution, social inequality, and instability (Thorbecke & Charumilind, 2002). When these associations reflect a conflict between economic and social stability, it is clear that economic development cannot last in a socially disparate environment (Barbier, 1987). According to the experience of developed societies, after a certain degree of economic prosperity, a society can identify intangible values such as empathy

and social equality, which allows success and economic stability to be sustained (Rezvan Abbasi, 2015).

- The relationship between social and environmental dimensions

There are symmetrical bivalent connections between environmental and social sustainability. Both struggle for finite economic resources that need to be transferred from the economic sector and utilized to promote social sustainability (Ahlheim, 2009; Rezvan Abbasi, 2015). This drives them to compete with one another. Instead of ensuring environmental sustainability by the excessive use of natural resources, a stable society is required. The collapse of society caused by environmental damage might spark a war for the few uncontaminated areas of land and freshwater left (Rezvan Abbasi, 2015). Consequently, environmental and social sustainability compete in the short term but complement each other in the long run.

3 Shaping factors in polycentric regions: Specific geographic, topographic, urban social and functional conditions

3.1 The polycentric city-region concept

Van Houtum and Lagendijk (van Houtum & Lagendijk, 2001) argued that the Polycentric is not a brand-new concept and is traditionally employed in urban and regional planning as an alternative to monocentric development for specific cities. In recent years, polycentric urbanization has received attention, but not as a definition of a specific urban form in any location or country. In European planning studies, a special issue on PURs[9], Dieleman and Faludi (1998b) argue that polynucleated urbanization (PU) applies to all post-industrial towns. To support their claim, they refer to Hall's "Modeling the Post-Industrial city" (P. Hall, 1998)

Hall, as cited by Pred, emphasizes how the "informatization" of the economy has led to a greater emphasis on high-value services. Hall argues that modern cities are increasingly globalized and characterized by many centers within a single functional zone. Improved transit options, congestion, and high costs in central business districts have led to the development of separate urban centers in most post-industrial cities.

Polycentricity has emerged due to the shift to a sophisticated service economy, which has altered the significance of metropolitan centers and how spatial infrastructures are utilized. PURs are expanded outside of (mega)cities by Dieleman and Faludi (Dieleman & Faludi, 1998b). Many connected venues are used for regional conventions. Europe's dense urban structure creates polycentric urban zones that are geographically distinct from the continent's traditional metropolises like Berlin, Paris, and London.

[9] Polycentric urban regions

Nonetheless, the idea of polycentrism is not defined clearly or precisely by Dieleman and Faludi (Dieleman & Faludi, 1998a). A PUR is an interconnected, strategically planned region with historically and politically different urban centers separated by wide open spaces with little discernible pattern.

Kloosterman and Lambregts (Kloosterman & Lambregts, 2001) stressed the significance of microeconomic underpinnings in attaining a competitive advantage in today's environment. They argue that local conditions make the impact of globalization on economic activity distribution less homogenous than its processes. Differences between city-regions become more obvious in key economic sectors as intra-regional differences, such as economic players' natural and human heritage, highlight local construction, skills, and existing networks. This local heritage influences a highly specialized area in a variety of activities. This metropolis of "modern industrial sectors" (Scott, 1997) is an agglomeration of economic activity that establishes "effective demand thresholds" for success in particular fields (Porter & E., 2001). They consider proximity when identifying the economic and competitive borders of advanced city-regions. Economists have recently emphasized accumulation economies or economic localism, whereas geographers have emphasized the "actual place." Besides, Kloosterman and Lambregts (Kloosterman & Lambregts, 2001) also describe three parameters that differentiate polycentric from multicenter cities.

- They consist of several historically separate nearby cities (roughly within one-hour commuting distance).
- They do not have an obvious leading city dominating political, economic, cultural, and other areas. Rather, they consist of a smaller number of major cities comparable in size and economic significance and a larger number of smaller cities.
- Not only are the member cities geographically unique, but they are also political entities.

In addition, Haqjou (Haqjou, 2018), to develop a framework for strategic spatial planning in polycentric city-regions, specifies four dimensions for such city-regions as follows:

- The initial dimension is about the physical form. The region's historical form determines the concentration of people and employment, followed by a pattern of radial, linear, or circular flows. Cities have the same importance in polycentric city-regions, and the patterns of mobility among the primary centers include pendulum and reciprocity. These centers are divided by open spaces and agricultural lands.

- The second dimension is concerned with the issue of political identity. Collecting historically and politically isolated cities makes building a political entity in such city-regions difficult. It obscures the open spaces between them, whereas reaching a cohesive political identity is significantly easier in polycentric city-regions. Furthermore, Kloosterman & Lambregts (Kloosterman & Lambregts, 2001) highlight the relevance of these city-regions as an economic unit, as well as the need to develop an organizational structure that considers public and private players at the city level in polycentric city-regions.

- The third dimension concerns functional interactions. It relates to work division in polycentric city-regions. These city-regions should have a consistent economic climate so residents can travel around effortlessly. This will boost the workforce in the region, allowing the centers to become more specialized in the city-region.

- The fourth dimension is related to the polycentric city-region identity and cultural symbols. Many cities have historically had identity origins and tend to display a symbolic city symbol, such as the football team, architectural signs, famous personalities, and so on. Local media such as newspapers, radio and television programs, and billboards can also be beneficial in depicting these

symbols. The regional symbol should be used in place of these symbols in polycentric city-regions.

Champion's (Champion, 2001) research on the emergence of polycentric urban configurations identifies at least three distinct pathways via which such a metropolis can take shape (Figure 6, see page 54).

1. Centrifugal is the initial mode. When a city's continued growth imposes such severe strains (for example, rising land rents in the central business district and worsening access to the central area from ever more distant outer residential areas), the most affected production and service activities are pushed out to alternative centers, which may eventually combine or separately rival the original center in size.

2. Second, how the incorporation will take place. When a large urban center expands its urban field to include smaller centers in the surrounding area that were previously largely self-sufficient concerning employment and services, a more powerful catalyst for attracting extra non-residential activities is created, potentially posing an even greater challenge to the main original center.

3. The fusion mode. As a result of their shared increase in overall size and lateral extent, as well as enhanced transportation links, multiple centers of comparable size fused.

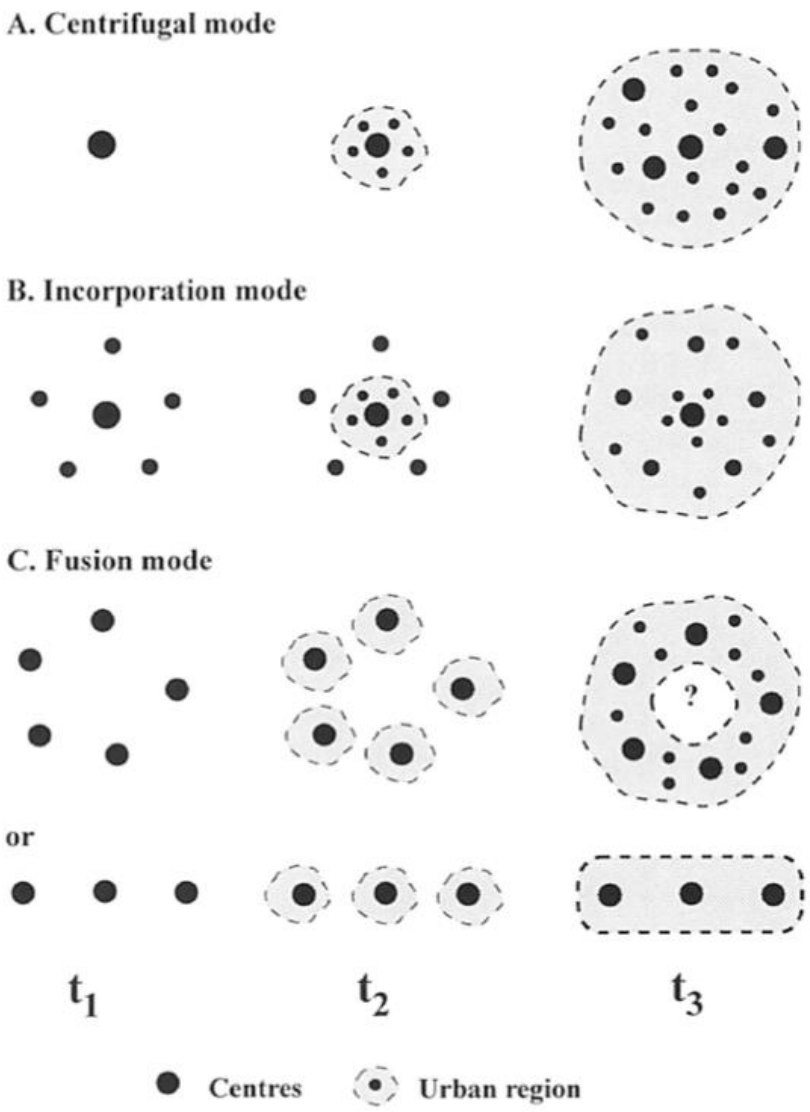


Figure 6 Thematic diagram showing the emergence of polycentric city-regions (Popjaková & Karvánková, 2018)

van Houtum & Lagendijk (van Houtum & Lagendijk, 2001), concerning the definition and emergence of the polycentric city-region, discusses that the polycentric city-region combines the concepts of urban solidarity and hierarchy. Polycentric city-regions rely on horizontal relationships between nearby cities to achieve a competitive advantage, and polycentrism is a planning idea, not a theory or hypothesis. This structure is supported by theory and experiment. The shape of polycentric city-regions is based on

mental conceptions of functional integrity, not empirical space logic. Previous notions were a model, theory, and planning concept. Also, they emphasize functional cohesiveness between cities rather than information, intangible assets, and electronic communications. As a result, a physical link between these cities in such a city-region is required. Also concerning the distinction of these city-regions is their distinct boundaries, as this polycentrism in a city-region depends on the presence of urban centers. Member of the urban system's territory is more important in the polycentric city-region. The realm constrains the urban system layout and focuses on the surrounding area's competitive position. Without a boundary around these cities, other notions focus on urban interconnection in time and place. Finally, they prioritize the regional identity and planning in building the city-region. This regional identity has strategic, cultural, and functional identities.

3.2 Polycentric city-region categorization

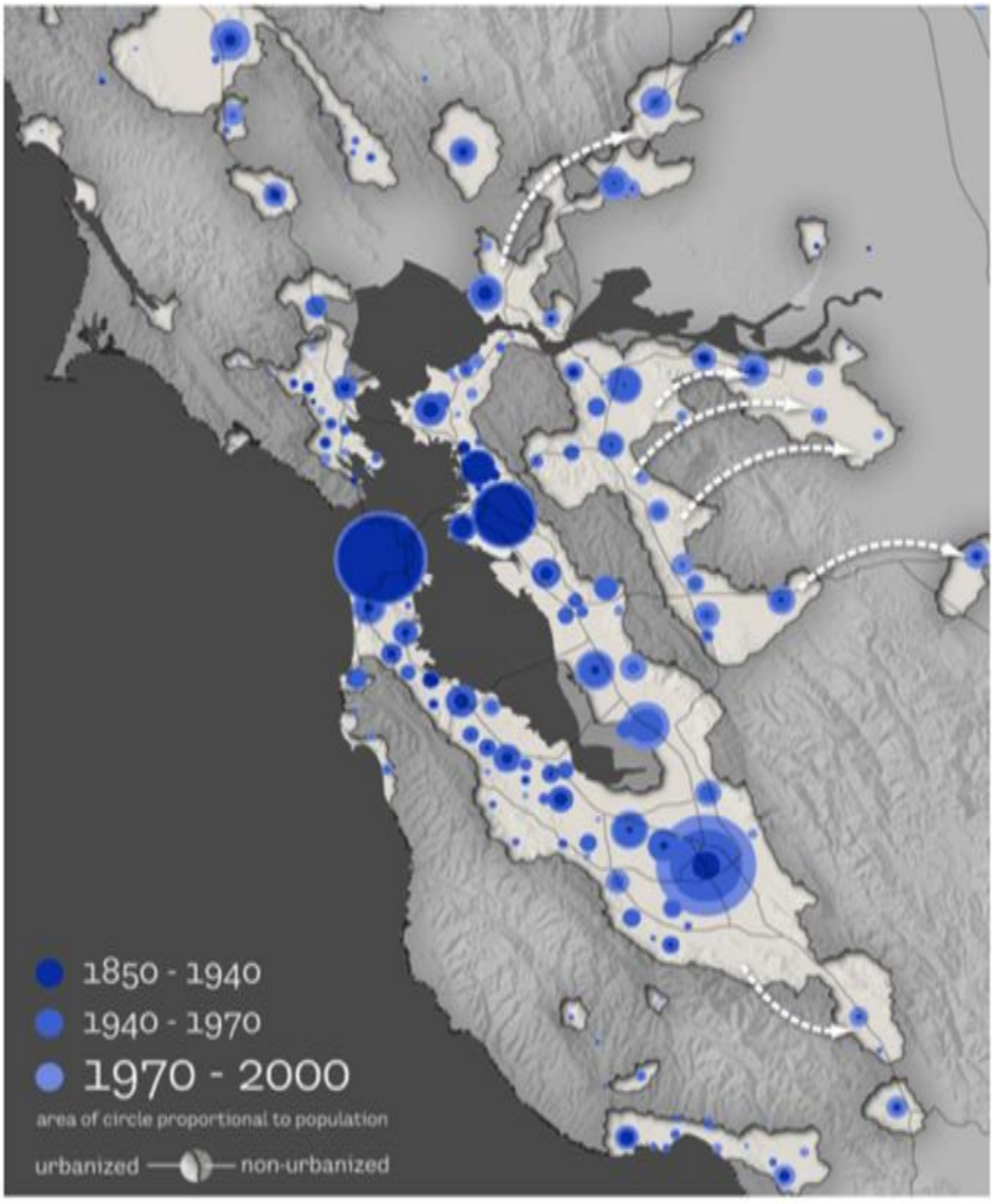
According to Haqjou (Haqjou, 2018), there are many ways to classify polycentric city-regions, including geographical classification, morphological classification, and functional classification.

1. Geographical classification

Most polycentric city-regions are geographically formed. This makes it possible for dense populations and settlements to occur in relatively level areas. Consequently, urban agglomerations might be located everywhere, such as in the plains, the mountains, or the coasts.

The Bay area is a varied area in northern California that includes San-Francisco, Auckland, and San-Jose, as well as numerous smaller cities, and can be used as an example of a geographically formed polycentric area. The gulfs of San-Francisco and San-Pablo border nine counties and 101 cities. Champion (Champion, 2001) calls this region polycentric, with a dominant central area and smaller periphery hubs. These

hubs, like San-Francisco, dominate non-resident activity, creating a linear city-region structure.



Map 1 The San-Francisco Bay area, coastal type (Urbanist, 2010)

2. Morphological classification

Polycentric city-regions can be classified into four patterns based on the establishment of centers and the pattern of morphology.

- Concentrated cluster pattern

The cities are clustered and centralized regions, often set up by the main centers and sub-centers. This city-region is shaped by the decentralization of population and employment and the growth of urban suburbs.

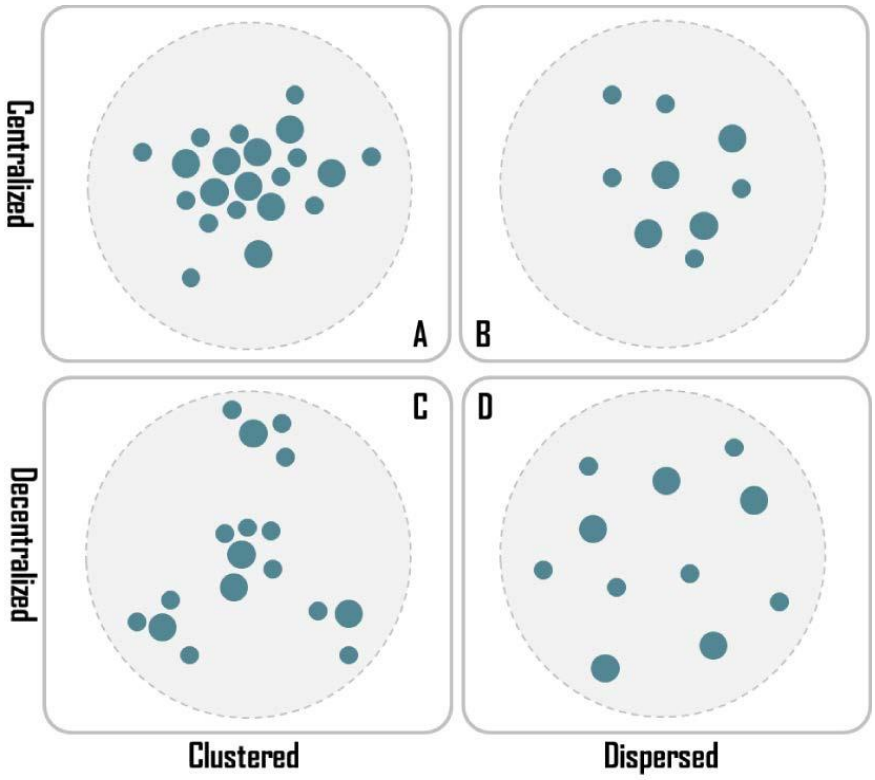


Figure 7 Concentrated cluster polycentrism distribution pattern (Rodrigue et al., 2016)

- Centralized scattered pattern

These city-regions are formed from many small and medium-sized cities, not from the growth of the suburbs, but by the horizontal extension of each of them and the unity between them.

- Decentralized cluster pattern

Such city-regions comprise medium and compact cities that have expanded their functional relationships from metropolitan areas and suburbs to create a regional identity.

- Distracted decentralized pattern

These cities are made up of several large and medium-sized towns scattered across the land, with large and small countryside filling the gaps between them.

3. Functional categorization

The following are some examples of functional categorization based on spatial scale, functional scale, functional domain, functional type, and socioeconomic dynamics:

- Spatial Scale Classification

According to (Green, 2007; Veneri & Burgalassi, 2012), the formal definition of polycentrism must be scalable. Research by Peter Hall (P. Hall, 1998) shows that polycentrism occurs at various spatial scales. In this sense, a region can likely be centered on two separate scales (national or regional) while still being poly-centered (e.g., at the urban size). According to Haqjou (Haqjou, 2018), there are at least two distinct forms of polycentric arrangements that can be distinguished in terms of spatial scale:

The first instance is a polycentric metropolitan city-region or cities extending beyond the immediate suburbs. It is a typical polycentrism configuration in the North American region, which consists of the central business sector contending for business centers.

The second model, which Faludi (Faludi, 2007) refers to as the "polycentric metropolitan city-region," comprises city-regions that lack a distinct hierarchy. Europe, particularly the Netherlands Randstad region, can be used to trace the origins of this city-region. However, in the second-centralized model, each country can be defined by specific geographic, cultural, economic, political, and special-scale planning.

- Functional scale

Different functional scales, ranging from a regional size to a national and global scale, can take place in Polycentric city-regions. The northwest of Europe is home to the most well-known instances of the Polycentric City-Region of global significance. The Rhine-Ruhr in Germany (Knapp & Schmitt, 2003) and Randstad in the Netherlands are examples of Polycentric city-regions that offer services worldwide (Bontje, 2021).

- Socio-economic dynamics
- Functional categories based on socioeconomic dynamics criteria, such as population growth and employment, stabilizing the share of population and employment, and stability and increase in population size or shrinking, can be used to categorize Polycentric City Regions.
- Functional Territory

Several functional categories can be used to classify Polycentric City Regions based on the type of relationships between centers and the strength of the center hierarchy. This category is also known as the Functional Territory category.

The major classification of the Polycentric Regions	Different types of classification
Geographical classification	Coastal Type
	Mountainous type
	Plain type
Morphological classification	Concentrated cluster pattern
	The centralized – scattered pattern
	Decentralized cluster pattern
	Distracted decentralized pattern
Functional categorization	Spatial Scale Classification
	Functional Scale
	Socio-economic dynamics
	Functional Territory

Table 2 Classification of polycentric city-regions

3.3 Mobility in Polycentric Regions

3.3.1 Polycentric Regions & Mobility System

The spatial organization of a polycentric city-region is known to influence the commuting patterns observed within that region (Haqjou, 2018). The polycentric structure provides several advantages, such as shorter travel times and cheaper overall transportation expenditures (Duarte & Fernández, 2017). Also, Small and Gómez-Ibáñez (Small & Gómez-Ibáñez, 1997) confirm this idea from another perspective and mention that monocentric cities inevitably become inefficient due to congestion in central locations caused by the expansion of metropolitan areas.

Moreover, Fujita & Ogawa (Fujita & Ogawa, 1982) argued that polycentric frameworks encourage the clustering of economic activities in subcenters, hence reducing the travel time of workers residing in subcenters and their surrounding areas. Fujita and Ogawa discuss the fundamental components of polycentric development, which promote the notion that polycentric cities emerge when transportation costs and congestion are considerable and also contribute to this circumstance. Both traffic congestion and high transportation costs contribute to this situation and lead to developing and shaping subcenters around the main centers and, in better expression, shaping polycentric arrangements.

A similar conclusion was reached by Aguilera & Mignot (Aguilera & Mignot, 2004) concerning the three most populous cities in France that people reside close to subcenters have an easier time commuting, albeit it is not as easy as if subcenters did not exist. Aguilera & Mignot (Aguilera & Mignot, 2004) conducted an innovative study investigating whether the polycentric urban structure produces job/housing colocation. Aguilera and Mignot used both approaches to analyze the data in this study. According to the synchronic findings of the study conducted between 1990 and 2000, polycentrism seems to shorten commuting distances in cities such as Paris, Lyon, and Marseille. On the other hand, its effect on how people get to work over the long term is diminishing. According to Aguilera & Mignot's research, subcenters gradually lose

the ability to self-contain and self-sufficiency as time passes. This makes it more difficult for subcenters to keep workers and to fulfill the labor requirements of locally owned businesses. Because of this, commute times have increased for people living both inside and outside the city limits. According to the explanation provided, the emergence of a subcenter would be the natural, more cost-effective, and time-effective response to the non-sustainable growth of the monocentric town regarding mobility. This response would align with the concept of a subcenter (Aguilera & Mignot, 2004). In large urban areas, commuter distances have steadily increased, while traffic congestion on most radial transportation axes has only worsened(Gordon et al., 1989).

It can be argued, however, that due to the monocentric city's spatial structure and an already concentrated employment center, residents tend to live in the suburbs. Thus, many commuters will flow into the center, generating suburbs. Rather than having a single point of origin, urban commuting would have multiple points of origin. Mostly, the commuting patterns of people living in a polycentric city-region are similar to those living in a monocentric city (Bertaud & Malpezzi, 2003).

In general, it can be said that Polycentric city-regions have two commuting patterns.

1. Firstly, according to (Alpkokin et al., 2005; Lin et al., 2012; Modarres, 2011), with this type of Polycentric City-Region, each sub-center generates commuting flows from all over the main center, which is the first pattern. Each center has some employment sub-centers on a comparable scale. People's travel patterns create an almost arbitrary distribution in their origins and destinations.
2. The second pattern, as discussed by (Aguilera & Mignot, 2004; Bertaud, 2009a; Bertaud & Malpezzi, 2003), happens when multiple centers exist, but only one is particularly concentrated and powerful. A jumble of random and circular patterns would characterize urban commuter traffic. There are various effects on commuting patterns due to the various spatial structure models, such as differences in commute times, trips, and modes of transportation.

At first glance, it seems not much has changed, except for the greater degree of urban expansion. In contrast, new urban structures evolved (Figure 8). On the one hand, the "centralized polynuclear expansion" that occurred from the growth of new towns or edge cities surrounding a central core can be described as "the interweaving of independent urban centers into a multimodal region or megalopolis" (Champion, 2001). This shows that previously independent clusters of medium-sized cities became more interconnected over time, establishing an urban network with many centers known as a "polycentric urban region" (PUR). On the opposite, Kloosterman (Kloosterman & Musterd, 2001) considers these regions to be more functional entities when evaluated on a regional scale.

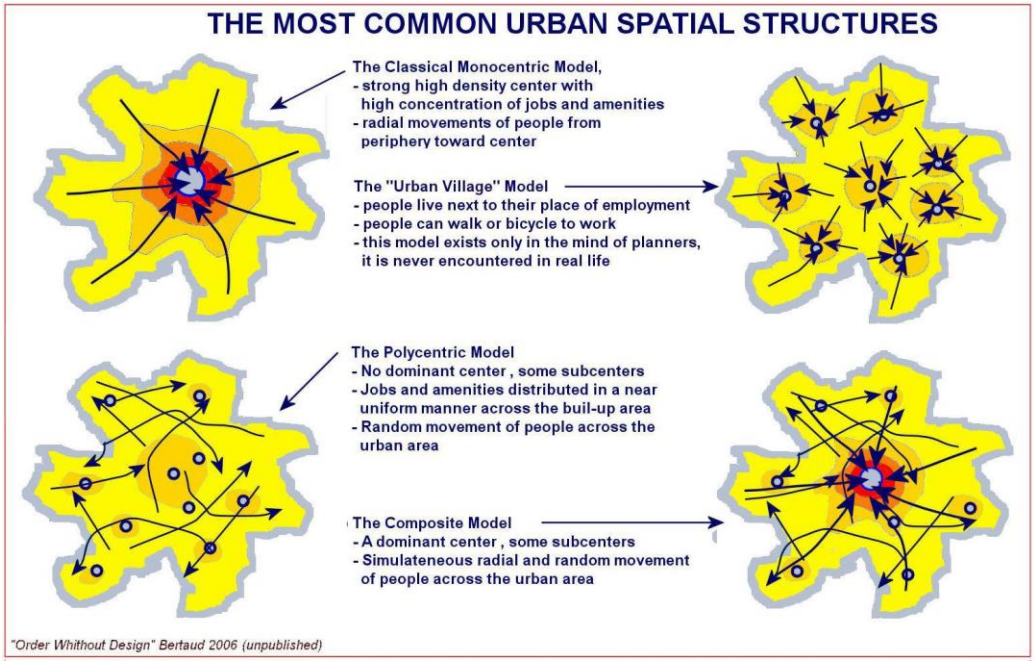


Figure 8 The variety of commuting patterns in both polycentric and monocentric spatial structures (Bertaud, 2009b)

In addition to presenting a theoretical model for the commuting structure inside the polycentric region, Hall and Pain (P. Hall & Pain, 2012) they examined many polycentric regions at the metropolis scale in Europe. As a result of their efforts, it was determined that as the population of the mega-city region decentralizes faster than

employment, it is safe to assume that the number of passenger trips, as well as the average length of such trips, will increase and that an increasing proportion of such trips will no longer be 'core'-oriented but will instead be 'edge'-oriented. This is because a growing fraction of these excursions will be directed toward the megacity's outskirts. The following examples will further explain this notion. In the case of Randstad, most passenger trips are short and have two primary concentrations: in the northern Randstad region, towards Amsterdam as the major trade center, with a secondary flow to Schiphol Airport, and in the southern Randstad region, where there is a two-way interchange between Rotterdam and The Hague. The only other large flow occurs between Nijmegen and Arnhem on the eastern border. Surprisingly, there are no large flows between the core Randstad cities, especially between the northern and southern "wings"; an integrated Randstad does not exist in this respect.

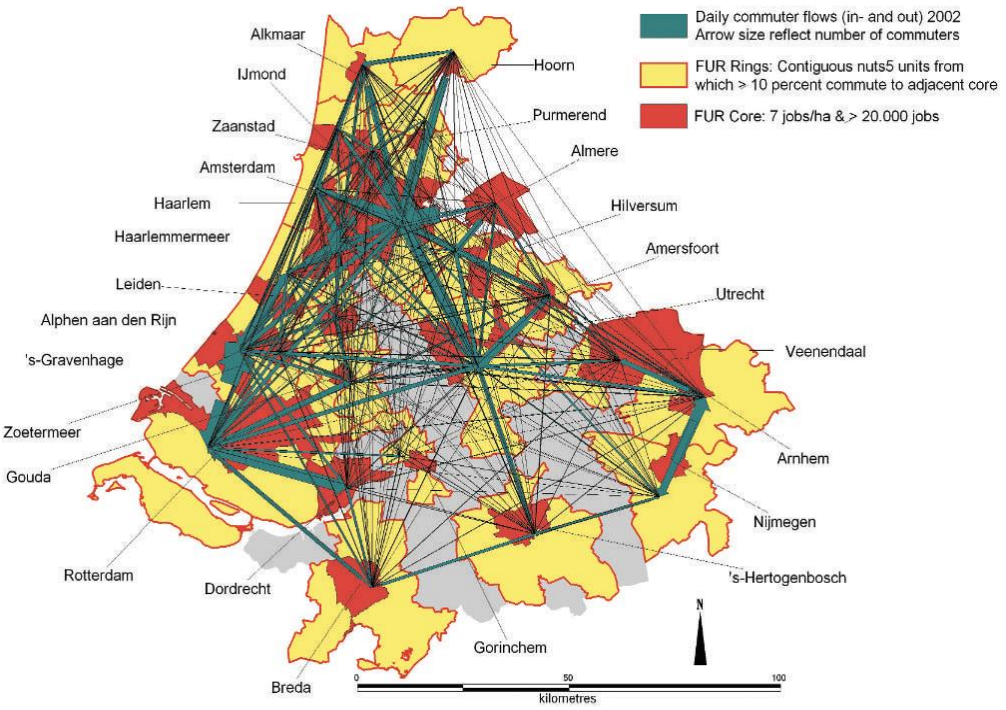


Figure 9 The Randstad polycentric mega-city region commuting pattern (P. Hall & Pain, 2012)

In Belgium, the dominant area of passenger flows is Brussels; nearby functional urban regions such as Charleroi, Mons-La Louvière, and Ghent send significant numbers, while more distant ones such as Brugge, Liège, and Hasselt-Genk send far fewer. In the center, the 'Flemish diamond' hosts numerous short distances traveling between functional urban regions. This traveling occurs particularly from one boundary to a neighboring border. Indeed, there are powerful reverse flows from larger functional urban areas like Brussels and Antwerp towards smaller ones; commuting more outside the functional metropolitan region is more restricted.

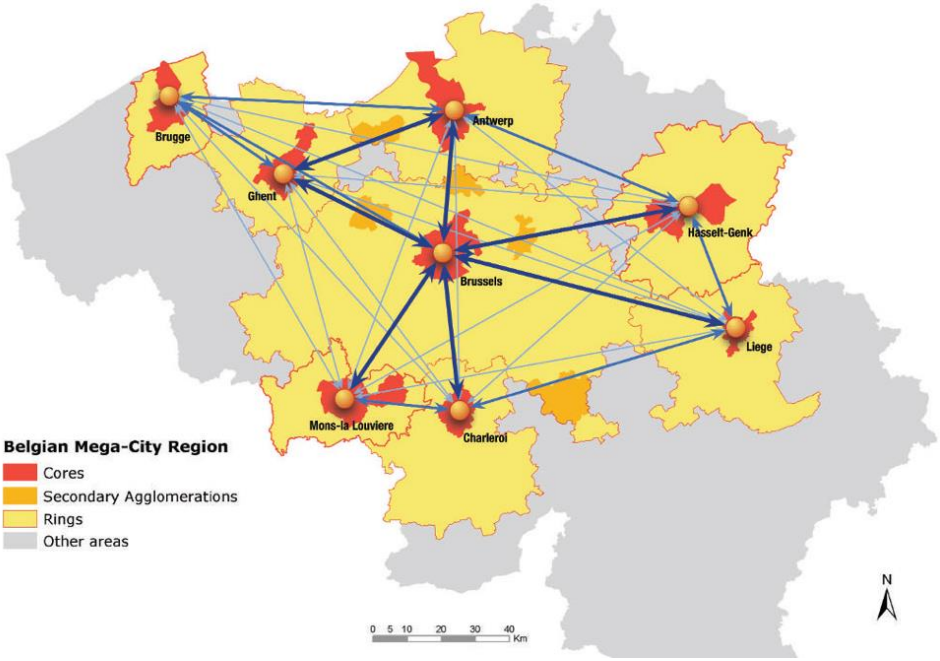


Figure 10 Belgian polycentric mega-city region commuting pattern (Hall & Pain, 2012a)

In Rhine-Ruhr, as presumed from the polycentric spatial structure, closely neighboring functional urban regions reveal great commuting connections. However, Düsseldorf city, regarding its capital and political function in the region, is the principal commuter

destination, getting significant flows from surrounding functional urban areas such as Duisburg, Essen, Mönchengladbach, Cologne, Krefeld, and Wuppertal. Further evident is a meaningful two-way flow within Cologne and Bonn. Similar two-way flows within the important Ruhr cities of Essen, Bochum, and Dortmund.

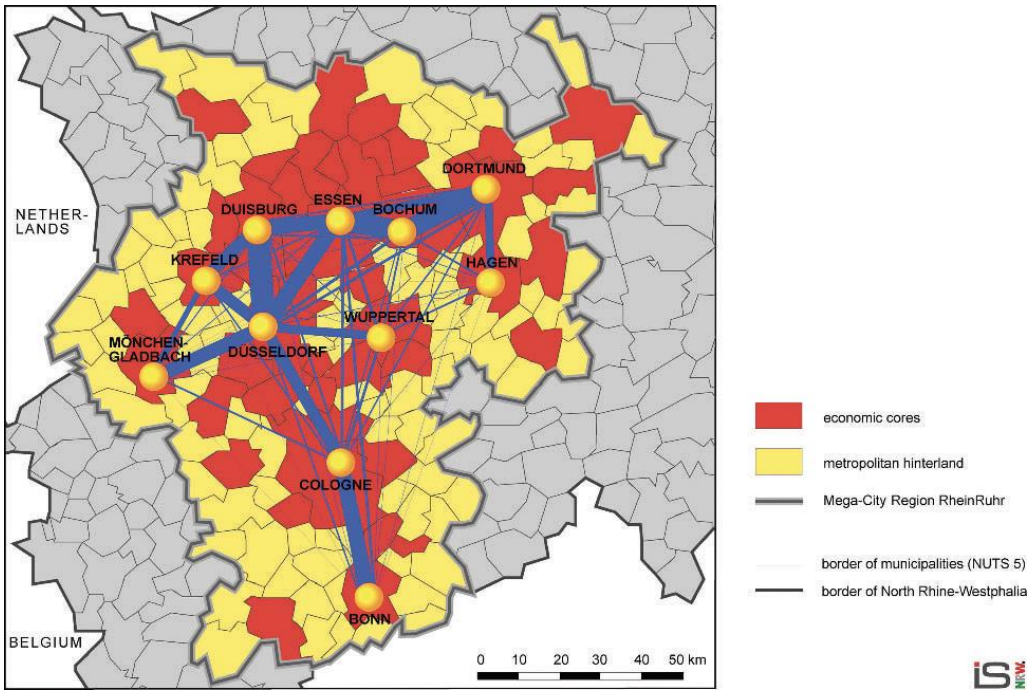


Figure 11 Rhine-Ruhr mega-city region commuting pattern (Hall & Pain, 2006)

Rhine-Main: Flows dominate the Rhine-Main case compared to the Frankfurt functional urban regions that employ about one million people, 200,000 commutes from the ring and 72,000 commutes from other functional urban regions into the employment core. Hither, as a way, distance is significant; there are big flows between neighboring functional urban areas, relatively little between peripheral ones such as Wiesbaden–Hanau or Mainz–Aschaffenburg. However, here, rivers and land boundaries demonstrate significant barriers to commuting.

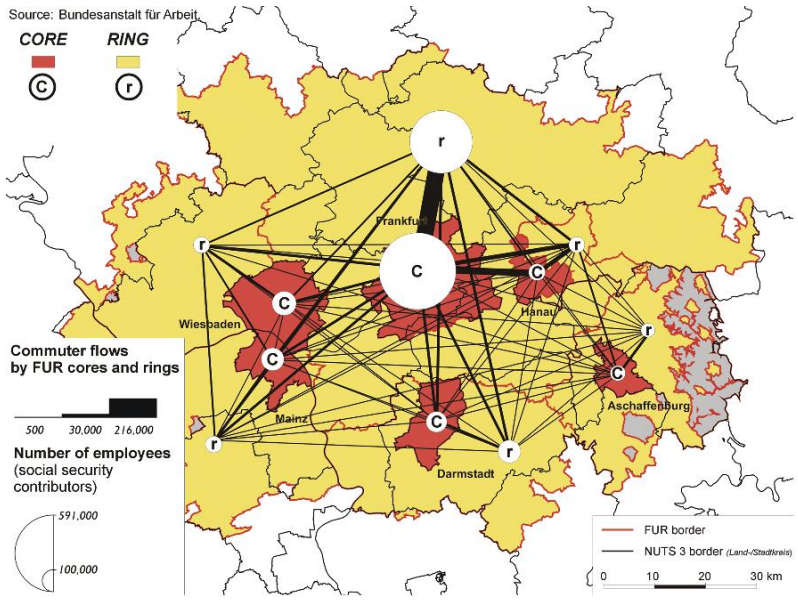


Figure 12 Rhine-Main mega-city Region commuting pattern (Hall & Pain, 2006)

Concerning the discussions, it can be concluded that while the low average density of the polycentric urban regions has certain advantages concerning quality of life, it is, at the same time, a significant restriction to implementing an efficient public transport system. However, this region has an underground metro. However, due to the lower densities in a polycentric urban region, there is often an insufficient economic basis for such metro-like systems, which depend on large transport volumes to be feasible. It is not a problem to achieve efficient connections between the main cities centers in the area. However, the transport to and from secondary centers in many cities in the polycentric urban regions and locations on the main cities' fringe is relatively time-consuming. As intense, rather criss-cross inter-urban commuting and a mixture of local and long-distance transport are other characteristics of many polycentric urban

regions, the threat of road obstruction and overloaded railway systems is evident. Admittedly, both are irrefutable problems of the polycentric regions. Also, concerning the structure of commuting patterns in different polycentric regions and the theoretical basis, it can be postulated that the type of commuting pattern in polycentric regions is pendular between the centers and fringe areas.

3.4 Spatial sprawl in regional context

3.4.1 The phenomena of urban sprawl

The earliest indications of urban sprawl and suburbanization can be linked to Ebenezer Howard's vision of garden cities in the early twentieth century (Kaumars Irandoost et al., 2018). Ebenezer Howard felt that constructing clusters of new cities connected to the primary city might resolve the issues of large metropolitan areas. Since the 1960s, urban sprawl's concept has been debated. Mohimi et al. (Mohimi et al., 2021) also argued long believed sprawl resulted from cheap land, excessive road building, and the overproduction of automobiles in American towns. However, urban sprawl is a worldwide issue, particularly in emerging nations.

The sprawl is defined as unplanned, single-use development with no planning. There is no functional land use mix, or the land use is not functionally tied to its surroundings (Eshghei Chharbrj et al., 2018). The sprawl is also defined as a low-density, linear or segmental pattern of land and construction development that is scattered, irregular, or isolated. However, socioeconomic criteria such as population growth, commuting expenses, and employment changes influence urban sprawl (Lv et al., 2012).

Also, according to Forsyth's (Forsyth, 2012) definition, sprawl is a type of suburban development distinguished by the presence of very low-density residential and non-residential settlements, the dominance of car-based transportation, the infinite development of urban land-uses to the outside, and the separation of land use categories. Furthermore, Colantoni et al. (Colantoni et al., 2016) argue that urban sprawl is caused by the sparse development of urban settlements to the outside, which includes the distribution or destruction of landscapes and ecosystems. Extending the landscape at a low density is a defining aspect of urban growth, particularly in industrialized countries (Cobbinah & Amoako, 2012). In addition, (Gottinder & Budd, 2005) define urban Sprawl as "random, low-density growth over a vast area, with single-family dwelling units dominating the residential pattern." The apparent consequences of this urban structure are increased social isolation, global warming

caused by pollutants from private cars, floods and erosion caused by more paving, the collapse of small farms, wildlife devastation and disruption, and so on. Jaeger et al. (Jaeger et al., 2010) have defined urban sprawl as "the external, unsystematic, and uncontrolled extension of urban land uses toward rural places as a result of urbanization overgrowth."

Urban sprawl has also been referred to as horizontal development, uncontrolled urban expansion, rapid horizontal city growth, and so on. Urban studies introduced the term horizontal urban distribution to describe sprawl in the last half-century. Sprawl is defined as the fast, widespread expansion of cities and small towns into rural areas. It also refers to unplanned and uncontrolled city expansion around cities, into villages, and along highways (Amanpour et al., 2020). According to Zebardast & Ghanoni (Zebardast & Ghanoni, 2018), urban sprawl can be associated with but not limited to the following features:

- Unrestricted external growth.
- Dense commercial and residential habitats.
- Expansions, both isolated and expanded.
- Land use power is being crushed in small neighborhoods.
- Public transportation dominance over private urban vehicles
- Inadequate centralized planning and land monitoring.
- Long-term and linear commercial development.
- Distinction of various types of land uses.
- Dependence on the elimination process and financial pursuit for low-income housing.

3.4.2 The impact of Sprawl on sustainable regional development

Current urban growth provides a significant challenge to sustainable development, particularly given the issues linked with peri-urban (Cobbinah & Amoako, 2012). The United Nations' Agenda 21 and habitat agendas outline urban sustainability goals such as "a compact urban form, the preservation of open space and sensitive ecosystems, reduced automobile use, waste, and pollution, the creation of livable and community-oriented human environments; decent, affordable, and appropriately located housing, improved social equity and opportunities for the least privileged, and the development of a restoration" (Arbury, 2005; Spiliotopoulou & Roseland, 2020). The relationship between spatial patterns and sustainability is a popular topic in current environmental studies (Wu & Zhang, 2018), but despite the apparent simplicity of the relationship between urban form and sustainable development, Jenks et al. (Jenks et al., 1996) contended that it is far from simple. Internal and exterior urban growth can be informally separated into two categories, each of which results in a different type of spatial pattern (Weber & Puissant, 2003), and in the following, Rahnama (Rahnama & Abbaszadeh, 2006) in their research mentioning spatial pattern related to external growth mostly is characterized by sprawl, whereas internal growth is characterized by the emergence of more densely compact cities.

Over the last decades, strains on land and resources are growing as well and when it comes to urban planning, efficient resource utilization, and the distribution of infrastructure efforts, the urban sprawl is considered as a possible danger to sustainable development (Sudhira et al., 2004). In this regard, substantial research has been conducted (Bekele, 2005; Z. Cheng & Hu, 2022; Hasse & Lathrop, 2003; Hogan & Ojima, 2008; Morote & Hernández, 2016; Pumain, 2004), on the effects of various forms of urbanization in developed and developing countries particularly urban sprawl. As a result of urban sprawl, unsustainable urban growth patterns have emerged from social, environmental, and economic viewpoints, in which each of them represents one of the pillars of sustainable development and is briefly discussed below.

- Economic dimension

Urban sprawl has many effects on the economic structure of cities including higher transportation costs, a decrease in urban vitality, the loss of agricultural and forestry land, the destruction of natural areas that sustain the tourism and wildlife industries, increased tax burdens as a result of the higher costs of constructing and maintaining roads, utilities, and schools, the loss of the rural characteristics that make many communities appealing to homebuyers, and an increase in air pollution are just some of the negative economic effects of sprawl (Rahimi Fatemeh et al., 2017).

As people move out to the suburbs and smaller towns, many larger cities and towns find that their populations decline as the empty land around them accumulates (Kaumars Irandoost et al., 2018). Population is shifting out from central regions and into more rural and recently developed places and as jobs and middle-class families leave the older neighborhoods for the newer ones, low-income and minority employees in those regions become increasingly geographically isolated from economic opportunities (Wei & Ewing, 2018). Meanwhile, rural areas and those dependent on agriculture are particularly hard struck by the economic consequences of sprawl. Meanwhile, rural regions and those that rely on agriculture are hit hard by the economic repercussions of sprawl. According to Saberifar et al., (Saberifar et al., 2020) findings, this trend's negative implications in the form of transportation costs and urban infrastructure towards urban inhabitants are greater than those in the form of income and employment opportunities for rural residents. The villagers have to bear the weight of this responsibility.

- Social dimension

Aside from the severe environmental and economic consequences, urban sprawl has significant social costs. These expenses rise with the displacement and separation of urban neighborhoods from the city core, as well as the construction of urban suburbs (Mousavi Mirnajaf et al., 2018). Indeed, urban sprawl, which has a significant negative

impact on the environment mostly due to land consumption, has no social costs, but population relocation is the first outcome of urban sprawl that has an impact on social networks (Mousavi Mirnajaf et al., 2018) and it is impacting on life quality and social capital on the societies (Nguyen, 2010; Wei & Ewing, 2018). Urban sprawl and expansion affect education, life opportunities, mobility, health, and access to public services (Nechyba & Walsh, 2004). Urban sprawl has exacerbated racial and gender disparities in access to jobs, public services, and urban amenities and also residential segregation (Zhao, 2013) According to the findings of the study, sprawl reduces exercise and increases obesity, and also stress and tiredness are major negative effects that sprawl has on people's health (Olanrewaju & Adegun, 2021).

- Environmental dimension

Unsustainable urban growth, such as urban sprawl, contributes to environmental degradation and climatic change in densely populated areas (Mansouri Daneshvar et al., 2019a). Further, it is possible that urban sprawl can alter the climate and lead to catastrophic weather events; urbanization and urban sprawl harm biodiversity and surface temperature (Emadodin et al., 2016). Furthermore, Bazrkar (Bazrkar et al., 2015)points out that urbanization has been the primary cause of climate change in recent decades. Urban sprawl's environmental impact in developed countries has been studied, too, confirming reduces open space and causes poor air quality (Bhatta, 2010). The effects of urbanization on the environment have a significant bearing on climatic and hydrological shifts (Sharma et al., 2016), and findings lent credibility to the notion that urban sprawl could influence climate changes (Mohan et al., 2020).

This is because of a chain reaction that begins with the effects of urban sprawl on development and continues through increased mobility and fuel consumption to increased emission of greenhouse gases like ozone concentration and long-wave flux in the urban atmosphere, which together are the primary cause of rising temperatures (Doherty et al., 2009; Kuttler, 2008). Temperature shifts across Iran's many inhabited regions demonstrate the impact of urban sprawl. Also, expanding heat island effects

from increased urbanization can have consequences beyond just raising average surface temperatures. This link further supports the hypothesis that urban sprawl may have an impact on such temperature shifts (Mansouri Daneshvar et al., 2019).

4 Three polycentric regions: European examples as learning fields

Policymakers and urban planners in developed societies, facing challenges at different scales from neighborhood to city and region, adopt different methods to overcome the problems. In the meantime, in the regional dimension, the European Union has a comprehensive insight into the entire union and member countries' national approach. However, at the same time, it specializes in developing regions in the form of a polycentric model. Considering the capacities of member countries in this union, specific missions have been designated as regional growth poles and development catalysts in regions of Germany, the Netherlands, and other members. This has prompted the reconfiguration of historically polycentric regions and, in some instances, fostered the emergence of areas with specialized functions, collaborating on a macro scale with other polycentric zones of the union. This section will discuss the three regions of Stuttgart, Rhine-Ruhr and Randstad with relatively successful experiences in polycentric and integrated management in the European Union.

4.1 Stuttgart region

4.1.1 Introduction

Stuttgart is located in Baden-Württemberg, Germany. The 3,654-square-kilometer area includes Stuttgart and five counties (kreise): Ludwigsburg, Esslingen, Göppingen, Rems-Murr, and Böblingen. About 2.7 million people live in 179 cities, towns, and villages. Stuttgart is one of Germany's most densely populated urban districts, with more than 700 people/km2. Within 200 km of Stuttgart, 20 million people live. The region's urban organization is polycentric. Many mid-sized municipalities surround Stuttgart with different historical and economic features (with a population of about 590,000 inhabitants). Esslingen (89k), Ludwigsburg (86k), Sindelfingen (60k), and others. Stuttgart lies in southwest Germany, near France and Switzerland. The Stuttgart region has a high income and purchasing power, a low unemployment rate (6.2% in 2006), and a flourishing real estate market. The region still needs houses and infrastructure. The region's job market attracts national and international migrants. Around 20% of Stuttgart's population is foreign-born, mostly from Turkey and southeast Europe. Integration of foreign migrants remains a concern (Jessen, 2009). Figure 13 shows Stuttgart, Germany, and its surroundings.

Stuttgart is one of Europe's most economically vibrant cities. The region had its first economic crisis following World War II in the early 1990s. With 56,000 auto sector jobs lost, the area is conscious of its vulnerability due to its dependence on industries like the Car industry. Mid-90s modernization and streamlining were effective. Deindustrialization is expected to continue and impact Stuttgart in the future. The regional strategy aims to diversify the economy and reduce its vulnerability by boosting R&D[10]. Regional policies aim to keep the region attractive for investment, living, and working. Urban regeneration and

[10] Research and development

revitalization will become fundamental to urban policy in this region (Jessen, 2009). Reorientation of spatial planning strategy in Germany and Baden-Württemberg in the early 1990s led to treating Stuttgart metropolitan as an area including several administrative counties and municipalities. Stuttgart, Rhine-Main, Hamburg, and Berlin are seen as engines of socio-economic development in European integration. In this reorientation, Baden-Württemberg areas were expected to integrate into the European economy, while Stuttgart was expected to boost economic competitiveness. To achieve this goal and to allow the Stuttgart economic region to be defined as a regional player speaking with one voice, the Association of the Stuttgart Region was created. The Association of the Stuttgart Region (VRS[11]) and Stuttgart metropolitan region are a paradigm for reorganizing derived political boundaries regarding regionalization of socio-economic links and economic restructuring. The VRS is an example of innovative governance structures and organizations strengthening old politico-spatial methodologies. The VRS aims to innovate and improve political, administrative, and spatial planning frameworks to utilize regional potentials in the locational competition for investments and jobs (Heeg, 2005).

[11] The German term, "Verband Region Stuttgart" or in English, The Association of the Stuttgart Region

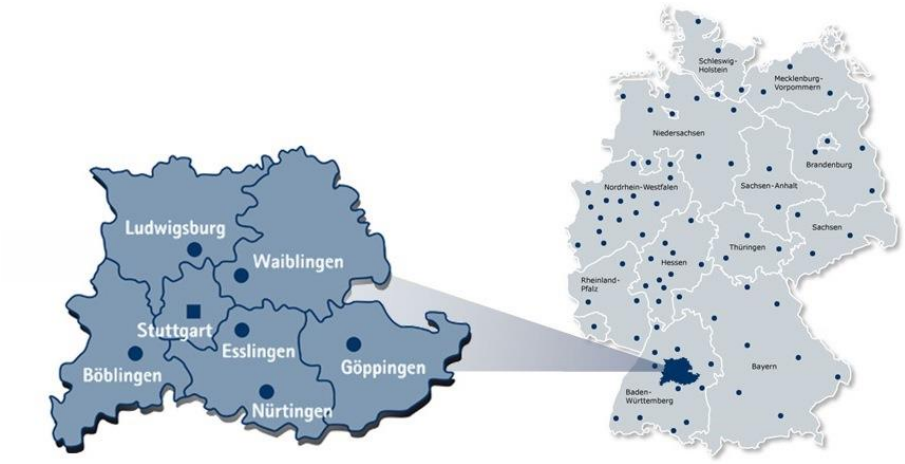


Figure 13 The Stuttgart region and surrounding area

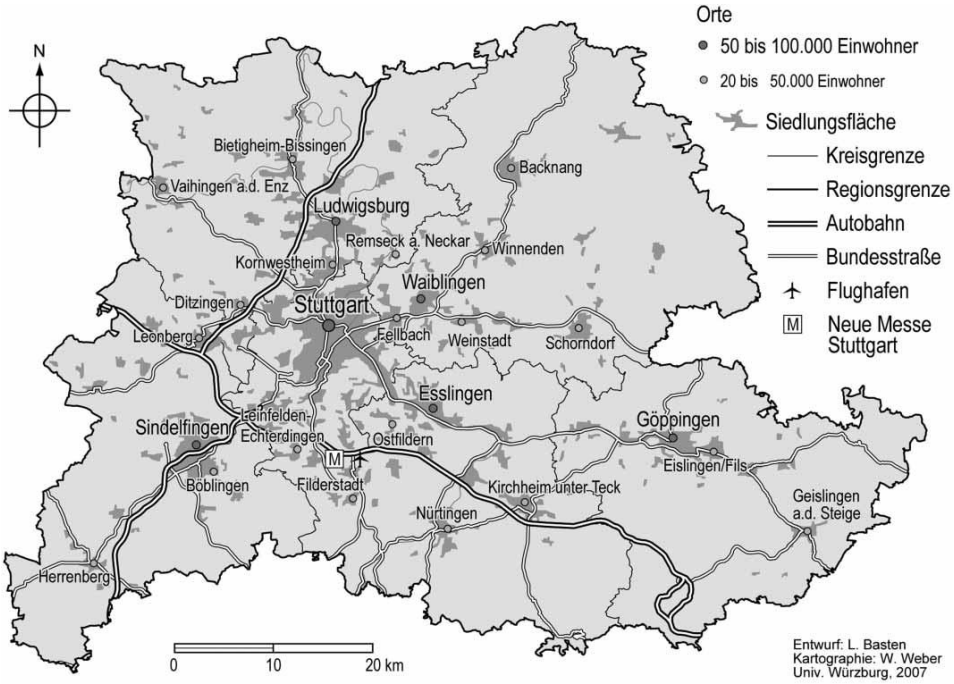


Figure 14 Stuttgart Metropolitan region benchmarks (Steinacher, 2009)

4.1.2 Changes in the regional imagination and VRS

Heeg (Heeg, 2005) considers Baden-Württemberg's economic prosperity depends on Stuttgart's geographical and economic competitiveness. In the early 1990s, the Baden-Württemberg government formed an advisory council to investigate Stuttgart's economic and corporate decline. This suggestion sparked disputes about Stuttgart. Robert Bosch Foundation publication (Müller & Kruse, 1994) states: "Whatever the long-term repercussions of German reunification and EU expansion on the German southwest, the Stuttgart region will face heightened competition from German and European regions." In a 1994 paper by Friedrich-Ebert-Stiftung, it is questioned if the structural change would harm Stuttgart. The Stuttgart metropolitan region must compete with key German cities, determine its place in the national and international urban hierarchy, and test its strength against other European pioneer economic regions. Political players in Baden-Württemberg and the metropolitan region felt the economic obstacles were Baden-Württemberg's fundamental difficulties because the Stuttgart metropolitan region was the engine of Baden-Württemberg's economy. This analysis shows a regional shift. Spatial planning no longer sufficed to modify regional potentials. Instead, proactive policy tools for the region were needed. An agreement was made to characterize the region inside one institution to avoid geographical misunderstanding. The debate modernized political organizations and institutions.

In German federalism, regionalism denotes regional entities under 16 federal states. In this way, legislative regionalization has two reasons. Regional sub-divisions serve administrative purposes. Baden-Württemberg has four. Their suggested approach considers historically grounded sensitivities and regional identities, Baden and Württemberg's historical and cultural distinctions being the most prominent. Below, regions can be regarded as functional regions, a viewpoint connected with geography and planning based on urban or metropolitan areas. Regional planning, which covers state and local regions, follows both. Post-war regional planning (including city-regional or metropolitan planning) reflects the

1960s and 1970s planning excitement. In many public policy and planning problems, the regional size is preferred above the state or local scale. In Baden-Württemberg, regional planning was institutionalized along with a reform and territorial merging of municipalities and counties in the 1970s (Basten, 2011).

Baden-Württemberg created 12 planning agencies in 1973. The fundamental duties of these public organizations were bringing out and revising regional plans and continuing Baden-Württemberg's spatial development and subject-specific plans (Heeg, 2005). Before discussing Baden-Württemberg's planning institutions, it is important to explain the German planning system context: regional plans integrate state-level spatial and economic goals with municipal land use plans. Any regional plan must follow the state's spatial plan (and its aims and objectives cannot conflict). These plans are replaced and updated every 10-15 years. In Germany, towns and municipalities are extremely independent, but their legally required land-use and building plans must adhere to the regional plan's aims and policies. They should also respect development axes, economic centers, and open space conservation. Sectoral plans (e.g., transport) should also achieve regional goals and objectives. Border regions must coordinate objectives across state lines (Frank & Morgan, 2012).

Baden-Württemberg created a two-tier regional system after establishing public planning enterprises: the first for general administrative reasons (regional districts) and the second, with fewer spatial objectives, for regional planning. Regional planning's main role is preparing a regional plan (land use and development) to implement state development policies and plans at the regional level, creating a framework for local municipal plans which is in the German language is "Baden-Württemberg's Landesplanungsgesetz." Baden-Württemberg's regional associations are public companies composed of counties, and regional assemblies make decisions. The state has delegated regional planning to local government companies (Basten, 2011). Initially, the Neckar Regional Association planned in Stuttgart. This organization handled Mittlerer-Neckar (Mid-Neckar Region). It

includes 179 communes in Stuttgart and Böblingen, Rems-Murr, Esslingen, Ludwigsburg, and Göppingen (Frank & Morgan, 2012). The Neckar Regional Group (Regionalverband Mittlerer-Neckar), renamed Regional Association Stuttgart (VRS) in 1992, is more than a regional planning association for the Stuttgart region (Basten, 2011).

Fiscal and decision-making issues were an institutional weakness. In arguing Stuttgart's economic location, restricted capabilities did not seem appropriate to meet the issues. The economic and demographic boom in Stuttgart's surrounding administrative districts led to a disorderly development of the Stuttgart metropolitan region's transport infrastructure, communities, and economy. In 1991, the Baden-Württemberg government created goals and requirements for the Stuttgart metropolitan region: a 'European region Stuttgart' should serve as a model for testimony and representation for investors not only in Baden-Württemberg or Germany but in Europe and internationally (Singh, 2017). Political and economic players promoted the reform of regional associations and joint entities such as public transit, waste disposal, and other urban and regional management duties. The administration, especially the Ministry of Trade and Commerce, reformed the institutional architecture. At the time, the goal was to create a single institution with broad duties and decision-making power.

Baden-Württemberg's state statute gives the VRS more political authority than the other regional planning organizations. This wide power of the VRS is based on the proportional representation of the central city and five counties in the Regionalversammlung (Regional assembly). The Regionalversammlung was Germany's first directly elected 5-year regional parliament. Since 1994, only Großraum Hannover has had this system (Jessen, 2009). This rapid transformation offers the region distinct qualities in the state. The movement was motivated by the automotive/manufacturing industry's economic downfall. Population pressure, especially from area enterprises, led mayors and councils to transfer

authorities and resources to the new agency. It boosted regional economic development coordination (Heinelt & Zimmermann, 2011).

4.1.3 Tasks and Policy Fields

The VRS has a greater mission than regional (planning) groups. Regional planning is a legal requirement. The 1994 act and its later amendments designate six additional legal responsibilities for the Stuttgart region: waste management and disposal, framework landscape planning, planning for a landscape park, transport planning, public transit network, economic development, and tourism marketing. Also, the VRS has received more volunteer tasks for trade fairs, parliaments, cultural or sports contests, and the landscape park project. The organization is a key player in a variety of regional policy issues. The three regional assembly committees mirror VRS activity sectors (Basten, 2011). In particular, the VRS's responsibilities fall into different categories but are not limited to regional planning duties, regional open space framework and environment planning, regional transportation infrastructure and public transport.

4.1.4 Regional planning duties

Formal planning responsibilities exist (determines settlement patterns, development axes, commercial and retail development locations, and protected open space). Landscape framework planning, a prerequisite for the regional plan, includes an inventory of land and water resources, links landscape to climate change mitigation, determines areas for open space preservation, and the conception, planning, and implementation of a landscape park for the region, and parts of waste management. As regional planners, the VRS should establish and maintain a regional plan that interprets the Baden-Württemberg state framework's land use, growth, and environmental goals. When drafting local plans, cities must follow the evidence-based regional plan. Since it mandates land uses, it must balance local municipalities' growth goals and the requirement to locate undesired land uses. The VRS has sectoral planning duties in landscape planning, transport

planning, and waste disposal management as part of a regional framework to provide regional balance (Frank & Morgan, 2012).

4.1.5 Regional open space framework and environment planning

The principal instruments of the regional plan play a pivotal role in configuring the landscape and preserving its inherent natural productivity. These considerations are elaborated within the open space framework (Landschaftsrahmenplan). One instrument prioritizes specific land uses over others, while the other safeguards land against alternative uses. The classification of locations facilitates flood management, prevention efforts, and the protection of natural resources. It also encompasses safeguarding designated areas such as protected agricultural zones, habitats, forestry areas, and regions critical for drinking water sources. These tools contribute to the establishment of regional green corridors, buffers, and open space networks. The focal objectives of open space and landscape planning are integral to the overall regional plan. Specifically, the strategy aligns climate change mitigation with the development of green infrastructure. The Strategy calls for protecting and maintaining the region's forests and limiting deforestation to emergencies. Any forest loss must be mitigated nearby.

Vegetated open areas are sources of more cooling fresh air and should be used to mitigate air pollution and urban climate (such as urban heat islands). Landscape plans evolve concurrently with regional plans, including open space plans and designations. The second plan enhances the long-term objective of establishing the Stuttgart region landscape park, providing citizens with ecological biotopes and recreational possibilities. Municipalities must contribute considerable land for cross-municipal park development and execution. The VRS does not implement the plan top-down. The opposite uses soft tools like economic incentives to engage the towns of the region. Several step-by-step sections are planned and

implemented, and the landscape park Neckar and Rems' masterplans are complete (Frank & Morgan, 2012; Steinacher, 2009).

4.1.6 Regional transportation infrastructure and public transport

The VRS plans regional transport and operates Stuttgart's regional public transportation systems. It develops regional commuter rail services (S-Bahn trains). The organization may plan and provide regional transit services, improving coordination and communication. The VRS also produces the regional plan, allowing early integration of regional land-use planning, transport planning, and commuter train procurement and avoiding inter-agency disputes and bottlenecks. The 2009 regional plan states that Stuttgart's transport system should assist regional plans. Transport infrastructure must be upgraded to produce a future-oriented, resilient, functioning system that functions and combines diverse transport modes.

The VRS manages and operates the regional light rail system, with six lines totaling 195 km. The network covers four of Stuttgart's five counties. Night bus coverage is also provided. Passengers can use one ticket for buses, trams, and national rail network local trains. The transportation system is funded by fares and German government subsidies for regions and county service levies (Frank & Morgan, 2012).

Considering these widespread transport planning goals, the VRS was an early advocate and is now a minority partner in "Project Stuttgart 21," a grand urban project developed in the mid-1990s to improve the Stuttgart-Ulm rail line, decrease travel times to Munich, Vienna, and Milan, and connect and integrate the Stuttgart region into the EU high-speed rail system. Investments were secured and approved in 2007 (Jessen, 2009). The VRS is a small project stakeholder. Most money comes from German Rail (Deutsche Bahn) and the state. The Stuttgart 21 project has overshadowed the VRS-related region's infrastructure debate. Stuttgart 21 is a large-scale infrastructure and urban redevelopment concept aimed at

utilizing up to 100 hectares of valuable inner-city property by transferring the railway tracks of the present limited train station underground and transforming it into a thorough station with fewer tracks. Rebuilding the railway site is expected to meet a third of the city's housing needs in 20 years. Using a brownfield site for new dwelling units in a city with limited space allows planners to conserve greenfield areas desperately required to alleviate the city's heat island impacts and smog. The site's master plan calls for an expanded city park, office, and commercial fields. Stuttgart 21 had the most major dispute between residents and the state since 1953 when Baden-Württemberg was created (Frank & Morgan, 2012).

In Stuttgart, the Stuttgart Regional Public Transportation organization or in German term "Verkehrsverbund Stuttgart" with the abbreviation VVS, determines public transit. The VVS operates public transit and plans and builds new railway lines with the VRS. The VVS was founded in 1978 and has been a public transit association since 1995. The VVS operates 41 commercial and state-owned transportation businesses in Böblingen, Esslingen, Ludwigsburg, Rems-Murr-Kreis, and Stuttgart. These municipalities cover 3,000 km2 and have 2.4 million persons.

The VVS includes all regional public transit modules, and its pricing applies to all. German public transportation is pleasant and appealing because of the integration of urban, regional, and national components. This coordination encompasses urban public transportation services, timetables, and tickets. Bus and train transfers are smooth in time and distance. One ticket can be used for a metropolitan journey (Buehler, Jung, & Hamre, 2013). This integration and coordination of diverse modes of transport (railway, metro, light rail, bus) and enterprises (41 in the Stuttgart region) are vital for acceptability and ridership. A single business provides public transit in the region, so passengers have one ticket, one organized timetable, and one reference for journey planning. As in many German cities with a regional transportation association, daily, weekly, monthly,

and yearly tickets are discounted. It especially appeals to commuters who use public transit as a car alternative.

4.2 Ruhr region

4.2.1 Introduction

Ruhr region is the most urbanized region in the North Rhine-Westphalia state of Germany (Figure 15), and it is a polycentric city-region. Around 5 million people live in big cities (5 cities – Cologne, Essen, Dortmund, Düsseldorf, and Duisburg with over 500,000 citizens) and medium-sized cities and 12 cities with over 200,000 residents, together with a tremendous number of smaller towns near each other.

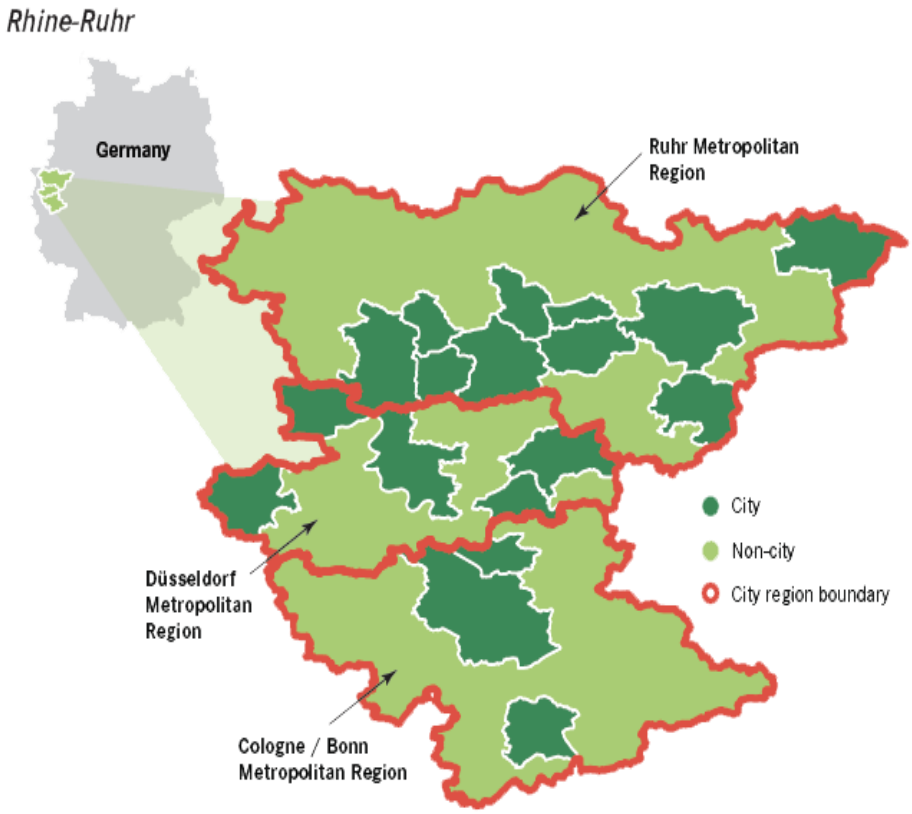


Figure 15 Rhein-Ruhr region and its boundaries within German territories

"Diversification" is an essential component of Rhein-Ruhr. This region is separated into two axes: the Rheinschiene region, which includes Düsseldorf, Cologne, and Bonn along the Rhine River, and the Ruhr region, which is also well known in German term as Ruhrgebiet, which consists of many cities, includes Duisburg-Essen-Bochum-Dortmund (Knapp et al., 2004). This research will focus on the Ruhr region axis since the Ruhr area is a separate economic, cultural, and political entity. The Ruhr region is a heavily populated corridor between Duisburg/Oberhausen. Strong urbanization processes arose along the Ruhr River up to the Lippe River[12] and beyond. These axes or corridors encompass a somewhat urbanized hinterland with significant commuting and consumer links to key cities. The remaining half of the Ruhr region may be considered a "big green area": Bergisches-Land[13] with its geographical and functional heart, the city-triangle Wuppertal-Solingen-Remscheid, and its hilly and sparsely populated hinterland Rheinisch-Bergischer District[14] (Knapp & Schmitt, 2003).

4.2.2 Spatial structure of the region

Some fundamental trends relating to demographic developments and settlement structures, spatial-economic performance, and mobility in the Ruhr region have a solid influence on the emergence of spatial structure and clusters in the region.

[12] The Lippe is the longest river in West Germany, with a total length of 220 kilometres, 193 of which are in North Rhine-Westphalia, Germany. It divides the East Münster Region from the Lower Hellweg and the Southwest Münster Region from the Ruhr region. Since Roman times, the Lippe (Latin: Lupia) has been used as a transportation route (Horst Pohlmann, 2017).

[13] The Bergisches Land is a hilly area in the German state of North Rhine-Westphalia. It is located on the northwestern border of the Rhenish Slate Mountains and is comprised of hills with rolling terrain, valleys and as well as forests.

[14] On January 1, 1975, as part of the municipal territorial reform in North Rhine-Westphalia, the Rheinisch-Bergische District was established from areas of the former Rheinisch-Bergischer District and the former Rhein-Wupper District. It encompasses the cities of Bergisch Gladbach, Burscheid, Leichlingen, Overath, Rosrath, and Wermelskirchen, as well as the municipalities of Kürten and Odenthal, within its current borders (Leichlingen, 2023).

- Settlements and demographic structures

Ruhr region has 5.1 million people. More than 6% of the German population and 50% of North Rhine-Westphalia state live in this area, a consistent population increase over the previous decade.

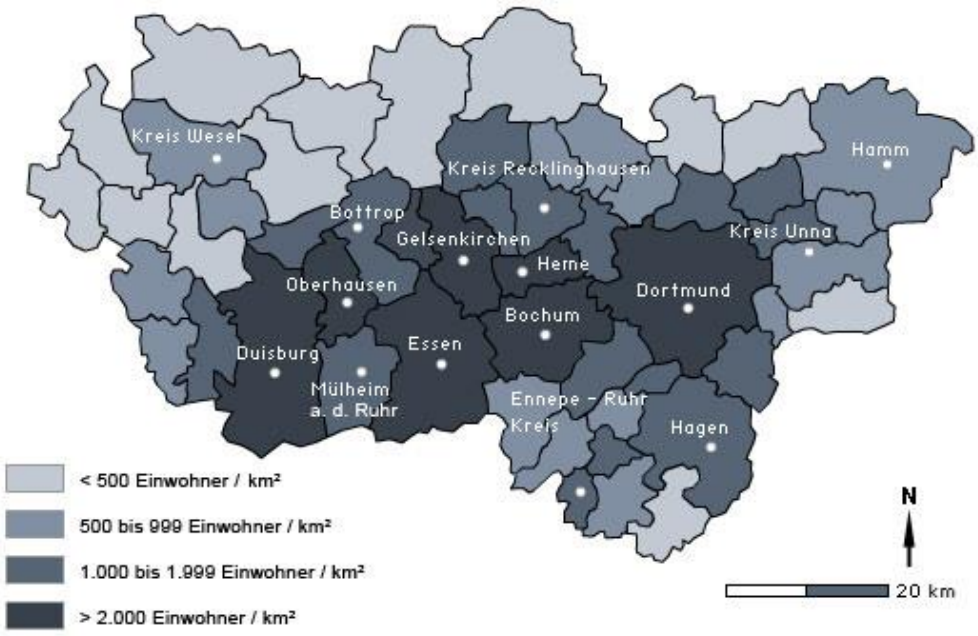


Figure 16 Settlements and demographic distribution of the Ruhr region (RVR, 2007)

- Accessibility structure

Ruhr region's integrated and dense rail network, the Rhein-Main region, the Randstad region in the Netherland, and Brussels/Flemish Diamond's polycentric region produce a highly linked infrastructure area. Huber (Huber et al., 2011), in accessibility research, presents the external accessibility of the Rhein-Ruhr region as excellent compared to other metropolitan areas in the Northwest Metropolitan

area. This extraordinary ability has two main causes. First, Ruhr region's central European location. Another is that it is well-connected to European road, rail, and high-speed railway networks. Cologne/Bonn and Düsseldorf airports are north-western Europe freight centers. Ruhr region has big ports. Duisburg is the largest inland port in the world because of its proximity to Rotterdam and Antwerp. Demand is growing because of the region's size or per capita infrastructure density.

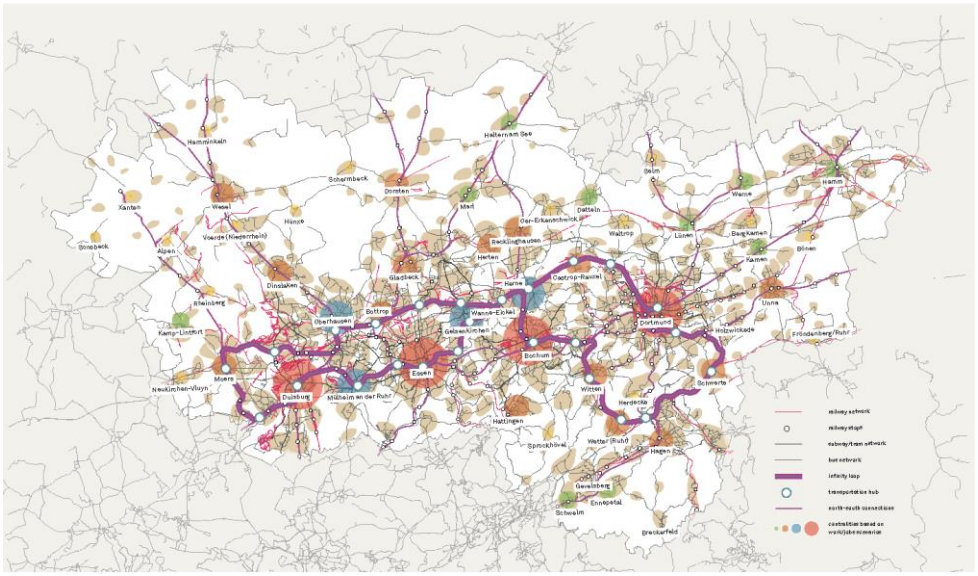


Figure 17 Accessibility infrastructure of the Ruhr region (Jansen & Schmidt, 2017)

Two separate infrastructure "corridors" correspond to the settlement structure and the Rheinschiene[15] and Ruhr region axes. The first corridor follows the Rhine River between Düsseldorf and Bonn. The other lines link Duisburg to Bonn through a three-lane freeway. Also, attempts have been undertaken to improve regional public transportation to cover a major portion of the Rhein region and Ruhr region and combine local systems, such as the Verkehrsverbund Rhein-Ruhr with abbreviation as VRR (VRR, established in 1980) and the Verkehrsverbund

[15] The term "Rheinschiene" refers to the Rhine Valley, a geographical and economic corridor that runs through Germany parallel to the Rhine River. It is widely used to describe the densely populated and industrialized Rhine region that runs from the southwest of Germany (near Basel, Switzerland) to the northwest (towards the Netherlands). Because of its economic, cultural, and historical value, this region is immensely important (Brinkhuijsen, 2013).

Rhein-Sieg with abbreviation as VRS (VRS, established in 1987). Regional public transport associations are necessary for polycentric city-regions with complex traffic flow links. In these traffic flows, city train stations are crucial nodes. Some significant initiatives have been or are being planned around Ruhr's major stations, as their quality and service provision are important to the future of German railways and urban growth (Knapp & Schmitt, 2003).

4.2.3 Policy and regional planning

- Concept of regional planning in Germany

Before moving on, we must briefly discuss German planning. Article 20 of the German basic law declares Germany a democratic, social, federal state. Constitutional statehood has two stages. The federal state has a central government (Bund) and various constituent states (Länder). The states have formed a federal republic of Germany (Bundesrepublik Deutschland). The 16 constituent states' constitutions grant them state authority and territorial and personal freedom. State authority in the federal state is split between the federation (Bund) and the member states (Bundesländer) (Pahl-Weber & Henckel, 2008). Figure 18 depicts Germany's administrative organization and dependencies.

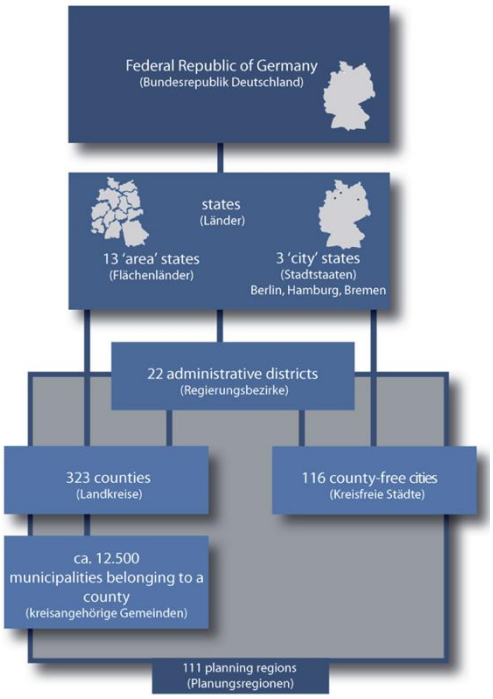


Figure 18 Administrative structure in Germany Source (Pahl-Weber & Henckel, 2008)

In the federal system, each federal state (Land) has its constitution and council, which it uses to shape the federal level. Cities and states will handle the planning issues. The federal spatial planning law (Raumordnungsgesetz, ROG) section 8-1 regulates the right and obligations to plan spatial development and execute regional planning in the states. Berlin, Bremen, and Hamburg are the only city-states without a regional level. "Landesplanungsgesetz" or federal state planning laws create the foundation for regional planning and its contents. These regulations state regional administrations' spatial and material planning competencies inside federal states. By law (Baugesetzbuch, BauGB), planning in Germany is delegated to municipalities.

"Baugesetzbuch" prescribes zoning via a municipally limiting land-use plan (Flächennutzungsplan) and the legally obligatory land development plan (Bebauungsplan), which was placed in 1960. The so-called Gegenstromprinzip controls the federal planning system. It balances and pressures responsibility

within the federal, state, regional, and municipal or county planning layers for top-down and bottom-up synergy. The opposing influence principle. The regional planning in this system is variable, defined in hierarchical and spatial institutional terms and the development of planning tools. This allows federal states to design planning stages and tools differently based on topography, population density, history, and planning culture, among other factors. Federal states provide a legal framework for regional planning and competencies. So, state planning plans for areas vary, excluding the state of Saarland and the three city-states of Hamburg, Bremen and Berlin. Also, Germany has 104 planning regions, which these planning regions have two categories. First, the Regional Association Act assigns planning competence to the local association whose planning areas match those of the local planning association. The second is a state-defined regional planning area. The second situation is the state of North Rhine-Westphalia, where the Ruhr region is located.

In the recent decade, the German government has worked to develop future-oriented spatial planning guidelines, especially for "metropolitan regions." Two materials were reviewed for these strategic guidelines. The first, the 'Raumordnungspolitischer Orientierungsrahmen' or guiding principles of spatial development, published in 1992, specifies the possibilities, principles, and methods for spatial development in the Federal Republic of Germany. The second one was published in 1994 as a federal document for an urban development framework plan or in German 'Städtebaulicher Orientierungsrahmen.' These works are a strategic framework for 12 large German cities (Keil et al. 2013). Also, these guidelines aim to establish and strengthen polycentric urban systems and stimulate cooperation within agglomerations or urban networks. Besides, the two guidelines tried to minimize agglomeration diseconomies in urban districts under development pressure like the Ruhr region, stabilize the settlement system in sparsely populated areas, and further boost greater Berlin's progression into the network of European metropolises (Knapp et al., 2004).

The Spatial planning policy framework, or in German 'Raumordnungspolitischer Handlungsrahmen' published in 1995, focused on its ramifications. This document defines new spatial units in German planning. The German urban areas in this document encompass six "metropolitan regions of significance on a European scale," namely Rhein-Ruhr, Rhein-Main, Berlin, Hamburg, Stuttgart, and Munich. They are spatial and high-performance locations with international impacts (Keil et al., 2013; Knapp et al., 2004). These six European Metropolitan regions are given special attention (EMR). Federal states and local authorities are asked to do the following mandates:

1. Improve international connectivity by plane, train, and infrastructure.
2. Promote inter-metropolitan networks and cooperation.
3. Encourage cross-border development concepts.
4. Coordinate federal and local infrastructure development in metropolitan regions.
5. Encourage inter-regional cooperation in natural resource conservation and mitigation areas.
6. Enhance regional marketing overseas.
7. Connect smaller cities to European metro areas.

Kunzmann notes that these actions are "generic," and the federal government has little desire to implement them. Policymakers could only use the designated action areas in the Länder or metropolitan regions (Knapp & Schmitt, 2003).

- Key issues for spatial planning in Ruhr

In 1950, North Rhine-Westphalia (NRW) was the first state in Germany to enact a state planning law (Landesplanungsgesetz NRW). This statute precedes the Federal Building Law of 1960 and the federal spatial planning law of 1965. After the 2009 revision of the North Rhine-Westphalia state planning law, Arnsberg, Detmold, Düsseldorf, Köln, and Münster developed planning regions. They have roots in the 1918 German Republic and have existed for decades. They are handled

by regional councils chosen by delegates of "district-free" cities (Kreisfreie Stadt) and counties (Landkreis), including smaller towns. They are in charge of formal regional plans created by the administrative planning board and authorized by the NRW official. Before discussing legal planning in the Ruhr region, it is important to consider the polycentric city-spatial region. For polycentric city-regions, spatial planning is key. Three main issues are considered for Rhein-Ruhr. "Internal and exterior access," "spatial diversity and open space," and "uneven spatial-economic growth" some geographical recommendations are provided to solve the issues.

- The basis for a regional approach

Effective regional cooperation hinges on functional interconnections and links. A thorough examination of these linkages is essential for establishing a foundation for strategic action and regional collaboration. Some experts, such as Blotevogel (Blotevogel, 1998), argue that mapping these interconnections within the Landesentwicklungsplan 1995 is inadequate. Blotevogel advocates for an additional geospatial design to articulate the goals of the Rhein-Ruhr region. This proposition may initially appear unconventional since metropolitan regions are often viewed as functional categories with specific spatial forms. However, Blotevogel contends that functionality holds greater significance, and these regions should not be confined by linear borders, as their characteristics are only indirectly associated with structural density.

- Organizing capacity

In conjunction with the Rhine area, the administration and institutions of the polycentric city-region Ruhr overlap and concur. As stated:

- Ninety autonomous towns (county-free cities, including 11 higher-order centers).

- Ten Kreise (regions or counties) and their constituent Gemeinden (municipalities/community) execution functions, which Kreise cannot undertake independently.
- Five Regierungsbezirke (district administrations) with five Regierungspräsidenten (district chief executives) who are responsible for sub-regional planning, together with four Bezirksplanungsräten (district/regional planning boards), which are made up of representatives from the counties and county-free towns, with 4 Regierungsbezirke touching the area of the polycentric city-region Rhein-Ruhr.
- 2 Landschaftsverbände (regional planning authorities), a higher communal association with responsibilities in the area of social infrastructure.

The Ruhr District Association of Local Governments, known as "Regionalverband Ruhr" in German with the abbreviation RVR, is an association of local authorities consisting of 11 towns and four regions in the Ruhr region, also known as the Ruhrgebiet in German. This association has a history dating back further than any other regional association in Germany. It was originally established in 1920 under the name "Siedlungsverband Ruhrkohlenbezirk," often abbreviated as SVR, which can be translated to "Ruhr Coal District Settlement Association" in English.

4.2.4 Ruhr district association of local governments (RVR)

Regarding the region's Ruhr District Association of Local Governments position, it is important to discuss its history, responsibilities, and associated matters quickly. Robert Schmidt, a key municipal official in Essen, established the first planning approach for regional difficulties in the western Ruhr area 1912. It is the first virtual Ruhr planning approach. 1910, the "National Park for Rhein-Westphalian Industrial Area" was introduced. This park covered Düsseldorf, Dinslaken, Essen, and Barmen-Elberfeld (today, a part of Wuppertal city). It addressed development control for nature conservation. Schmidt's Strategy

concentrated on residential area management and population growth distribution, encompassing housing difficulties and the partition of the industrial areas through the greenery. Aside from shaping partnerships, Schmidt, instead of official association and avoiding political strife among other local governments, pursued the idea of a voluntary municipal corporation with restricted control and functions (Reicher & Haase, 2018).

In 1920, after World War I, the German Prussian imperial government and the Ruhr area towns founded the SVR, the Ruhr Coal Regional District, Germany's first law-based municipal organization. This action was slightly copied from Greater Berlin ("Groß-Berlin"), founded in 1911. Due to its legal basis and poor public standing, the SVR gained planning rights within the Ruhr and Lippe rivers (north-south), the Netherlands, and Hamm (east-west). The SVR director had the same tasks as the directors of the five regional administrative districts. Director administrative authorization was separated into the departments of area management (Landespflege), regional management (Regionale planung), and land subdivision (Bodenordnung). In the 1950s, SVR focused on urban restoration and development plans. The region had 6 million people. Even though coal and steel production decreased after the late 1950s due to global competition, the SVR was a vigorous regional planning body during the 1950s and 1960s, completing big development projects like the regional waste management system or Wulfen New Town. As one of the first German regional plans, SVR produced a regional development plan (Gebietsentwicklungsplan 1966 des Siedlungsverbands Ruhrkohlenbezirk) in 1966. The state government assigned SVR this duty based on the recently enacted regional planning law (Landesplanungsgesetz) of 1962. This progressive plan systematized a region-wide system of green corridors using Schmidt's spatial concepts. Due to industrial decline, the regional planning law was updated in 1974 and 1979 to limit the association's planning power to certain skills and issues, such as the territorial greenways system. The weakening of the SVR was a chain reaction of the state's efforts to more firmly direct the structural

change of the region due to industrial loss by top-down sponsored policies (Reicher & Haase, 2018).

The Ruhr Area Municipal Planning Association, or in German Kommunalverband Ruhrgebiet (KVR), was shaped in 1979 to replace the SVR under the local government association Ruhr law (Gesetz über den Kommunalverband Ruhrgebiet). The KVR's first assignment was to achieve structural change, dampen social shocks, address environmental issues, and other objectives. 2004, KVR became Regionalverband Ruhr (RVR) (Ruhr District Association of Local Governments). Figure 19 (see page 98) is the RVR organization chart.

Further, beginning in 1979, the state bought brownfields through property funds (Grundstücksfonds) to control the clean-up and reconstruction of evacuated industrial sites, encompassing a large part of the Ruhr's settlement area. Since brownfields often contained dirty soil, they slowed the region's environmental and economic recovery. IBA International Building Exhibition (1989-1999) focused on the Emscher River Valley and its adjacent territories, 17 of 53 municipalities in the core of the Ruhr region. It was a state-directed program for regional regeneration. Over time, municipalities involved in IBA initiatives realized the benefits of inter-communal collaboration. In the Ruhr region, brownfield rehabilitation was done with more than 100 local infrastructure, housing, and other initiatives within the IBA and other regional organizations like the Emscher River Municipal Association (Emschergenossenschaft). The municipalities unified their efforts to reintegrate 70 kilometers of open sewage into the Emscher River's green space network. IBA projects were based on informal planning instruments for bottom-up cooperation, and consistent top-down financial steering and quality management by the state was one of the essential opening points for the immediate culture of collaborative regional planning governance in the Ruhr, which governs the region's current planning trajectory (Reicher & Haase, 2018).

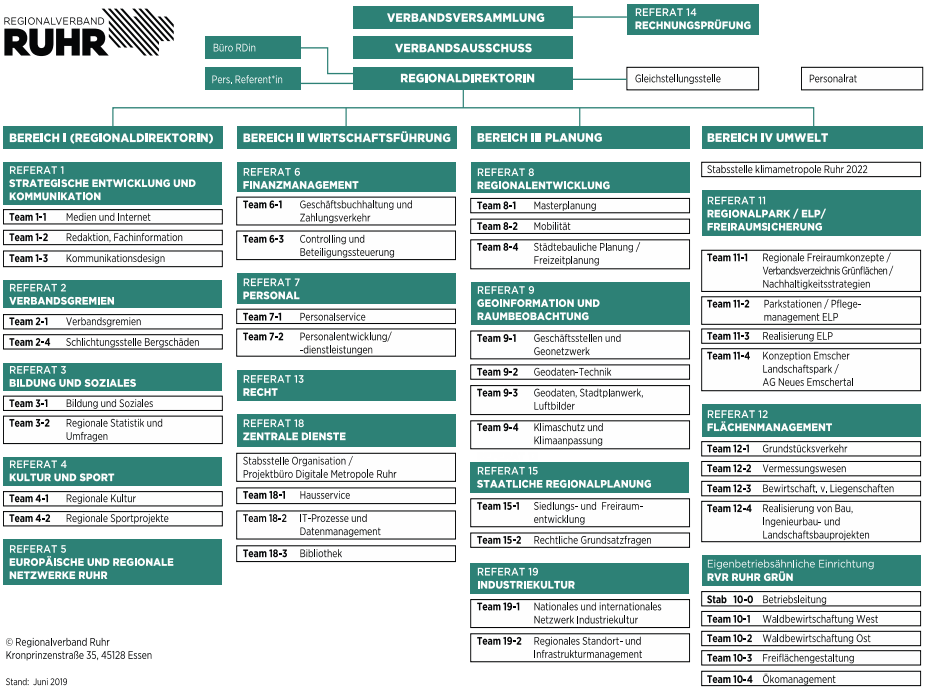


Figure 19 The RVR organization chart

Additional to these organizational structures, many regionalizing procedures have been tried in North Rhine-Westphalia to stimulate and improve cooperation and the implementation of jointly agreed projects at the regional level.

4.2.5 Public transport management in the Ruhr region and Germany

- German public transport management structure and organization

German public transportation is organized under the Transport Association system, which in German is called "Verkehrsverbund." One-Fare and One-Ticket is a network of integrated public transport services within a defined area. "Verkehrsverbund" has become a virtual trademark in Germany for cooperative alliances and many public transport services across alliance regions. Following the launch of the Hamburger Verkehrsverbund (HVV) in 1965, Germany is considered the birthplace of the alliance model. In recent years, the number of

Verkehrsverbund in Germany and other German-speaking countries like Austria and Switzerland has increased dramatically (Buehler et al., 2019; Pucher & Kurth, 1995).

- Definition of the term Verkehrsverbund

Verkehrsverbund means public transport association, and the collaboration patterns in this system vary by activity type and scope. The chosen form depends on factors such as the degree of subsystem interconnection and the region's spatial and geographical organization. In public transport management, the actual and political context is also crucial. Partial cooperation could be only coordination in specific subareas, such as bus, tram, and subway connections, a combined timetable, or tickets that can be used on any form of transport in the network. Verkehrsverbund is the most comprehensive public transportation organization as they have the most extensive contractual agreements because they require the most cooperation and integration. Primary responsibilities include setting and improving the combined fare system and organizing the network and timetable for all public road and rail transport in the collaboration region. Alliance organizations are umbrella legal entities created by participants and stakeholders. The alliance organization is usually legally independent and acts as a separate entity (Manfred, 2009)

- The collaboration models

The ideas behind cooperative public transport alliances influence local authorities, passengers, transport companies, and all involved actors. Making public transportation more attractive and cost-effective is a top priority. This movement was accelerated by the desire to integrate public transportation in German cities. From a passenger's perspective, the shift to a Verkehrsverbund model was crucial and resulted from individual transport companies operating separately within a city region. When the first alliances and collaborations began, creating new

suburban railway networks that needed to be connected to existing urban transport systems created a growing demand to interlink transport and fare subsystems in a given region. The Verkehrsverbund connects different carriers and local administrations to meet passengers' demands for an integrated transport network and easier access to public transport. When using multiple public transit subsystems, Verkehrsverbund makes sense. Carriers working together in a Verkehrsverbund want to improve their public transport systems. Ultimately, a range of passenger-attractive services should increase demand and fare revenue, improving profitability. The key is eliminating competing transport services and coordinating all available services more efficiently (Manfred, 2009).

Local and responsible authorities want a cooperative public transport alliance to limit public spending. Local officials often link transport integration with other political goals. Public transport organization and association creation are tools for spatial planning, regional development, and regulatory, social, or environmental goals.

- The creation of the first Verkehrsverbund

Early in the 20th century, public transport companies began to collaborate. Initially, this mostly involved one-off subjects like transition fares or transportation collaboration. Today's Verkehrsverbund achieves integration. Due to changes in spatial and settlement patterns, transportation structure, and urban growth in the 1950s and 1960s, more effort was made. In 1965, Hamburger Hochbahn AG, Deutsche Bundesbahn, and Verkehrsbetriebe Hamburg-Holstein AG founded the Hamburger Verkehrsverbund, the first German public transport collaboration (Buehler et al., 2019). The high number of passengers transferring between the three companies' multiple modes of transport prompted the collaboration. A new typical fare and actual collaboration brought customers real benefits. Hanover's Großraum-Verkehr Hannover (GVH) was founded in March 1970 and introduced a typical fare. The Münchner Verkehrs-und Tarifverbund

(MVV) was founded after the 1972 Olympic Games and had good experiences from other transport collaborations. The Frankfurter Verkehrs- und Tarifverbund (FVV) was founded in May 1974. In 1978, Stuttgart's Verkehrs- und Tarifverbund (VVS) began. In 1980, the first polycentric city-region in Germany, the Ruhr area, was established in cooperation with the Rhine area and the Verkehrsverbund Rhein-Ruhr (VRR). The VRR covered the region between Düsseldorf and Dortmund, which had 7.7 million people. Concerning public policymakers' proposals for improving and reordering the organizational structure for public transport and a federal Verkehrsverbund concept, three new Verkehrsverbund were established in the late 1980s: the Verkehrsverbund Rhein-Sieg (VRS), the Verkehrsverbund Großraum Nürnberg (VGN), and the Verkehrsverbund Rhein-Neckar (VRN). This Verkehrsverbund was only viable for the largest city-region in West Germany; other transport regions used less concentrated cooperation. The Verkehrsverbund seemed to end the collaboration creation phase in the late 1980s (Manfred, 2009). Figure 20 shows Verkehrsverbund's growth from 1967 to 2017.

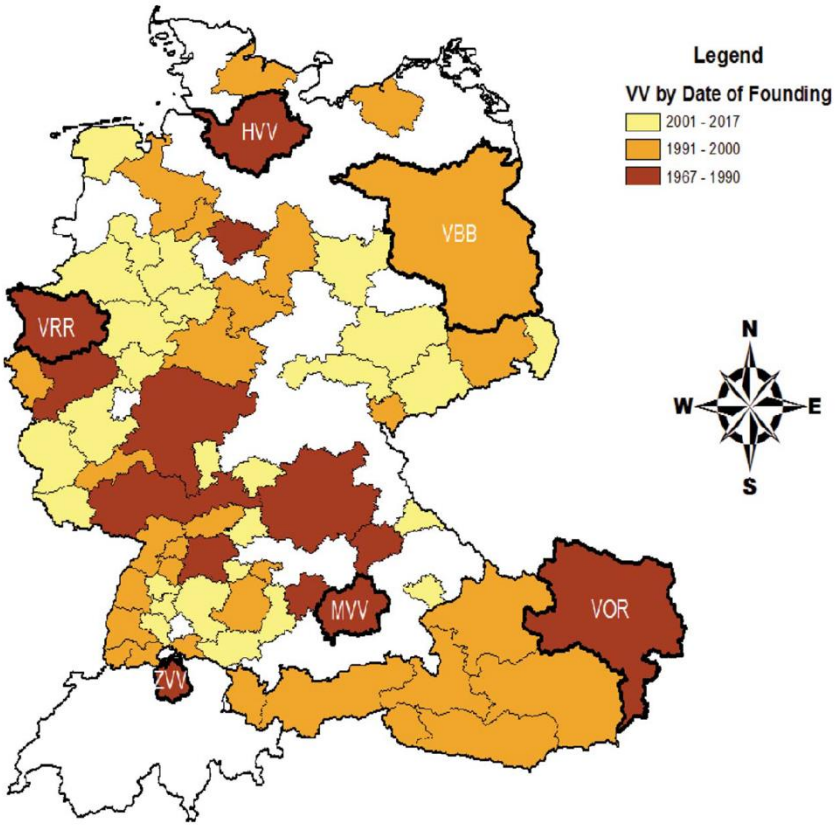


Figure 20 Verkehrsverbund (VV) expansion in Germany (Buehler et al., 2019).

- The impact of the regionalization of public transport

Until 1990, Germany's Verkehrsverbund organizations had the same structure and tried to balance the interests of public transport companies and Deutsche Bundesbahn (German Railway company). Local authorities' concerns and roles are reflected in the Verkehrsverbund structure, but public policymakers were absent from decision-making. In 1990, the Verkehrsverbund Rhein-Ruhr, as the first Verkehersverbund, restructured into a voluntary association of local authorities (Kommunalverbund) and shifted Verkehersverbund stocks from transport companies to local authorities. This VRR restructuring was a precursor to similar developments in other Verkehersverbunds due to the regionalization of public transport. Regionalization in the context of railway restructuring supported many public transport law changes in the 1990s. The entire public transport system

received a new legal basis following European decisions. The Railway Reorganization Act (Eisenbahnneuordnungsgesetz, ENeuOG) amended the General railways act (Allgemeines Eisenbahngesetz, AEG) as the basis for regional passenger transport and the passenger transport act (Personenbeförderungsgesetz, PBefG) as the basis for general public transport (Verband Deutscher Verkehrsunternehmen, 2010).

- The Verkehrsverbund Rhein-Ruhr

The Verkehrsverbund Rhein-Ruhr (VRR), Since 1980, has been one of the largest transport associations in Europe and fulfills various public transport tasks on the Rhine, Ruhr and Wuppertal and provides public transport services in the 16 independent cities and seven districts. The VRR follows the so-called three-level model as follows:

1. The political level-cities and counties

North Rhine-Westphalia law requires cities and districts to organize public transport. Municipalities in the operation area have formed two special-purpose associations to improve public transport. The VRR consists of 19 cities and five districts, and the Lower Rhine Local Transport Association (in German, it is called Nahverkehrs-Zweckverband Niederrhein with the abbreviation NVN) has two districts. Two special-purpose associations have transferred their public transport duties to Verkehrsverbund Rhein-Ruhr Public Institution (VRR AöR). Municipalities influence network decisions by sending politicians to two administration union association meetings. Members of the association meeting fill VRR's highest decision-making bodies: the Board of Directors, the awarding committee, and the advisory committees. The Board of Directors names VRR AöR's Management Board.

2. The Management Level Verkehrsverbund Rhein-Ruhr

Verkehrsverbund Rhein-Ruhr bundles network tasks and competencies. Its institutions link political and operational levels. The Management Board manages the AöR. The board of directors includes politicians from municipal special-purpose associations and four VRR transport company heads. The Board of Directors decides most local public transport issues. It also manages VRR AöR's board. Association meetings send members to AöR committees. Professional committees prepare board resolutions. Only the awarding committee decides on SPNV[16] competitions and existing transport contracts. The Advisory Board links management and operations. Municipal, private, and railway transport companies are integrated into the network structure and political decision-making.

3. The operational-level transport company

The VRR's operational level includes public and private transport companies and railroads. They have VRR contracts. "licensed transport companies in the Verkehrsverbund Rhein-Ruhr" (KViV) also design public transportation in the compound area. They work with VRR AöR in five working groups: legal, economic, marketing, tariffs and distribution, technology, IT and security, and local public transport management. VRR AöR and KViV agree on all transport company critical decisions.

- Financing of public transport

As so-called municipal authorities, the cities and districts in the VRR are obliged by law to provide appropriate public road passenger transport (ÖSPV). Public and private transport companies use buses, subways, or trams for this. The EU's Regulation (EC) No. 1370/2007 governs these assignments. In a metropolitan area like the VRR, where one area often blends into the next, transport links are

[16] Schienenpersonennahverkehr which in English is meaning "Local rail passenger transport"

close: transport companies travel in their respective urban or district areas and often in neighboring regions. Municipalities usually finance their own local public transport company and all driving companies. Municipalities, the VRR, and transport companies have complex relationships.

- The political bodies of the VRR

The collaboration area's cities and districts have formed task forces for local public transport. Cities of Wesel and Kleve form the Nahverkehrszweckverband Niederrhein (NVN). The VRR consists of 19 cities and five counties: Bochum, Bottrop, Dortmund, Duesseldorf, Duisburg, Ennepe Ruhr district, Essen, Gelsenkirchen, Hagen, Herne, Krefeld, circle Mettmann, Monchengladbach, Monheim, Mülheim a der Ruhr, Neuss, Rhein-Kreis-Neuss, Ober Municipalities send politicians to the two special-purpose associations' meetings and actively participate in network decision-making.

- The importance of the transport associations

Due to recent alliance formation, only a few German cities are outside a transport associations (Verkehrsverbünde) area. There are 60 transport associations in Germany with combined road and rail fare systems, and they are servicing nearly all urban areas and many small and medium-sized communities and conurbations. Transport associations cover two-thirds of Germany's surface area and serve 85 percent of its population. 90% of trips and fare revenue are generated within alliance areas, and it can be said now that transport associations offer most transport services within Germany.

There are often differences between alliances regarding size, population, and transport services. In the Verkehrsverbund Rhein-Ruhr area, 7.2 million people live compared to 190,000 in Kreisverkehr Schwäbisch-Hall. Berlin- Brandenburg

Transport Association (VBB[17]) covers 30,367 km, while Freudenstadt covers 800 km. In Baden-Württemberg, some alliances and cooperative alliance structures cover a single rural district, while VBB covers Berlin and Brandenburg. Also, in alliance areas, annual journeys range from over 1 billion in Rhein-Ruhr and Berlin Brandenburg to under 20 million in Vogtland and Hegau-Bodensee. Fare revenues are similar. The number of transport companies in an alliance ranges from four in Großraum-Verkehr Hannover to 150 in Rhein-Main-Verkehrsverbund. Verkehrsverbund, a transport association in Germany and the Ruhr area is a useful organizational prototype for preparing integrated public transport services over a large metropolitan area or surrounding states. Other progress indicators include increasing quantity and quality of services, increasing passenger levels, decreased subsidy needs as a percent of operating costs, and a stable or rising public transport mode division despite rising car ownership and driver licensing rates in Germany (Buehler et al., 2019). The Verkehrsverbund model has spread in German regional and local administration because it is flexible. Rhine-Ruhr is very polycentric, while Berlin, Hamburg, and other German regions that benefit from Verkehrsverbund are monocentric.

4.2.6 Development control and regional green belt

- Regional green belts in Germany

Regional planning protects contiguous open space from uncontrolled land consumption and development. To address these challenges, regional green belts represent green and open places in the metropolitan region. Few studies have addressed the contribution of regional green belts in Germany to reducing land usage. According to Siedentop (Siedentop et al., 2016), regional green belts preserve open space in metropolitan areas. The analysis demonstrates that greenbelts protect open space in regional plans for Düsseldorf, Hanover, Stuttgart,

[17] Verkehrsverbund Berlin-Brandenburg

and Middle Hesse. Kretschmer (Kretschmer et al., 2015) offers open space and land usage factors in Germany. They present a rational framework for multidimensional investigations and regional planning to reduce land usage. Zepp (Zepp, 2018) presented a study on green belts in 42 German regional plans and concluded that, despite regional disparities, regional green belts are one of the most complete and beneficial parts of spatial planning. Due to the inextricable use of related terminology like green space, it has been required to define the Green Regional Belt in the German planning lexicon before addressing it in the Ruhr area. In this regard, the current definition of a Regional green belt in the German planning system is borrowed from (Pahl-Weber & Henckel, 2008; Zepp, 2018): "A regional green belt is a continuous expanse of land reserved for ecological functions or recreation and forbidden for settlement or other functionally incompatible uses."

- Regional green belts in Ruhr

Regional green belts were first developed in 1960s German spatial planning. Gottfried Schmitz and Joachim Gadegast were the first to use the term'regional green belts' in the Ruhr Regional Development Plan in the 1970s, according to (Erzner, 1995; Zepp, 2018). SVR set and described regional green belts. The first ideas to provide green belts for the Ruhr Region were developed in 1912 by the later founding director of the "Siedlungsverband Ruhrkohlenbezirk" (SVR) (Reicher & Haase, 2018). As a general concept and a planning kind, green belts have become an integral part of regional planning in the Ruhr Region. The "Siedlungsverband Ruhrkohlenbezirk" (SVR) Planning Atlas (1960) was a milestone in planning and open space protection in the Ruhr Region. Figure 21 marks the beginning of the Ruhr green belts.

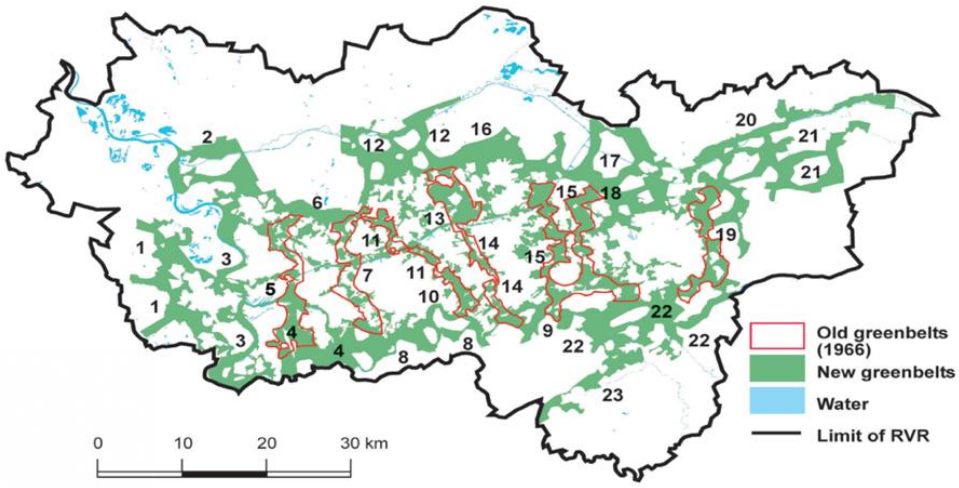


Figure 21 The regional green belt development in the Ruhr area from 1966 until 2017 (Zepp, 2018)

Concretely, Greenbelts separated Ruhr's industrial and residential regions. Zepp (Zepp, 2018) characterizes greenbelts as agricultural, forestall, and recreation zones. These green belts contained infrastructure, landfills, and spoil spots. North Rhine-Arnsberg, Westphalia's Düsseldorf, and Münster took over regional planning and green belts in 1975. Green belts are a feature of all regional plans developed since 1966. In this regard, the regional land-use plan for the cities of Bochum, Essen, Gelsenkirchen, Herne, Mülheim a der Ruhr, and Oberhausen conforms with the Federal Building Code and Federal Spatial Planning Act (Kanonier, 2004). Green spaces in the Ruhr Region promote air quality, provide leisure, and preserve water-generating regions, according to the RVR Planning Atlas. The regional development plan and RVR prioritize agricultural and protective greenbelts. Land use needed conservation and gardening. Landscape capacities and potentials were studied to adapt to the coal and steel industries. Green belts repaired brownfields in the 1980s. Master and local landscape plan Emscher Landscape Park showcases Ruhr green space preservation, rehabilitation, development, and qualification. The "Open Space Concept Ruhr Metropolis" fosters connectivity and links search areas to greenbelts (Zepp, 2018).

Considering Zepp (Zepp, 2018) and Siedentop (Siedentop et al., 2016) from the assessment of German regional greenbelt designations and Ruhr region green belts, it can be concluded that the regional green belt emerged in formal German spatial planning documents about 60 years ago, and they form an integral part of regional planning today. Green belts safeguard open space in urban and non-urban areas. Germany's greenbelt planning differs from foreign practices. Greenbelts control regional urban physical development. The physical development control zone forces the spatial growth of central cities and suburbs over a larger border. German planning is varied because there are few legal standards or government directives. This describes oscillations in greenbelt coverage and land-use consolidation.

Concerning the Ruhr Region, regional green belts were first mentioned in 1912 during the SVR's formation. During the Ruhr Region's growth, green belts were transformed for habitation, transit, and infrastructure. Losses are unevenly distributed. Future regional plans are considering new green belt delineations. Green belts would be expanded from 281 km2 (1966) to 696 km2 (2004) and 1103 km2 by continuing into less densely populated outlying zones. In the inner Ruhr area, where the original Regional green belts reside, an 'adaptive' decline may occur by reducing the previously occurring transformation to urban, non-open space land cover.

4.3 Randstad Region

4.3.1 Introduction

In the Netherlands, there are three levels of government: the federal, provincial, and local levels, respectively. The federal government sets the policy framework for spatial planning (long-term aims, general plans), whereas local governments have executive planning authority. The provinces must guarantee that local development initiatives comply with national policy goals and cooperate among themselves. For more than 150 years, the tiers of this system have undergone continual changes in urban planning tasks and responsibilities, and local authority is devolving.

This three-tiered structure has recently been questioned due to the "regional world." The organization's core ideas stayed intact over time. The 'regional problem' was addressed by promoting more municipal and, to a lesser extent, provincial collaboration (the number of municipalities reduced from 742 in 1985 to 467 in 2005 due to yearly mergers). Randstad is one regional innovation that does not fit the three-tier paradigm; others include big-city urban districts. The area includes 175 municipalities and four provinces (North Holland, South Holland, Utrecht, and Flevoland). This is unlikely to change in the foreseeable future. Municipal and provincial governments have advised and executed Randstad's planning since the 1950s. However, recent Randstad actors have entered the "discussion."

The Randstad-based "Deltametropolis" association has issued several Randstad-wide studies, discussion papers, and vision statements in the previous decade (more formal cooperation between the four provinces, the four largest cities, and their respective city regions). These documents are not legally enforceable but impact the government's perception of Randstad. They also reveal societal ideas and wishes. Only federal materials (including Randstad policies) are lawful. Every ten years, the Ministry of Housing, Planning, and Environment releases a white

paper establishing spatial policy limits for the coming decades. These stories show Randstad's growth. This spatial planning white paper now includes input from more agencies, boosting policy sector coherence. Economics, transportation, and agriculture publish policy papers (P. G. Hall & Pain, 2006). To a large extent, the regional development vision of Regio Randstad informs the national government's spatial Strategy for Randstad Holland. When it comes to city planning, Randstad is more forthright and confident. Forming a unified Randstad region of supplementary, specialized, and well-connected city regions is necessary to compete with the strongest European metropolitan areas, as none of the individual cities and city areas can do it independently. Randstad executives are impressed by the region's diverse polycentric structure. However, they point out that the city's lack of "points of excellence" and "feeling of place" indicates the need for a more holistic approach to development. The national government is unsure whether Randstad constitutes a metropolitan area (Thierstein et al., 2005).

As the site of more than half of the nation's economic activity, the nation's most congested rail- and highway networks, and some significant (and commercially viable) agricultural and natural regions, the Randstad receives appropriate consideration in these policy texts. Several provincial and local governments have passed plans. These focus on specific sections of Randstad and seldom touch on larger principles articulated in national white papers, "Deltametropolis" Association publications, and Regio-Randstad books (P. G. Hall & Pain, 2006).

4.3.2 Profile of Randstad

To further on the Randstad, it might be said that it is a network of Dutch cities. There is Europe's largest seaport, third-busiest airport, and second-largest Internet Exchange. Randstad's growth has been called the classic polycentric city since the 1960s, with an urban ring surrounding a Green Heart. The spatial design may have aided polycentricity (Zonneveld & Nadin, 2020). Randstad includes Amsterdam, Rotterdam, The Hague, and Utrecht. Seven million people live in North Holland, South Holland, Utrecht, and Flevoland. Randstad's borders are unclear, but it is 6000 km2. The urban layout includes rural Green Heart (Lambregts, 2009). Multiple local, municipal, and provincial administrations complicate the political and administrative system (Goess et al., 2016). Former KLM director Plesman invented the term "Randstad" in the 1930s after witnessing a ring of cities. Since the 1950s, limiting urbanization of the 'Green Heart' between cities has been a significant spatial strategy. Hall (1966) called the region a "global metropolis" and emphasized its worldwide competitiveness. Rotterdam is port and logistics, The Hague is international law, and Utrecht is research. Amsterdam is business and finance (Zonneveld & Nadin, 2020).

Despite Randstad's similar geography, policy goals vary. The Randstad and its two' wings' are alternately highlighted. Amsterdam, Utrecht, Rotterdam, and The Hague support the North Wing (Goess et al., 2016). Rotterdam's enormous ports relate to logistics and manufacturing, whereas Amsterdam and Utrecht are associated with the tertiary sector, which includes financial, cultural, entertainment, trade, and consultancy services. The Hague is dominated by government and international trade. Even the wings are too complex for government involvement. South Wing and North Wing ended. Utrecht's North Wing was detached from Amsterdam. The South Wing was established in Rotterdam, the Hague, and 21 surrounding municipalities and cities (Goess et al., 2016). Figure 22 shows Randstad's region location in the Netherlands.

Figure 22 The approximate position of the Randstad in the Netherlands (upper left) and the main cities

However, in current Dutch spatial planning, Randstad remained a polycentric metropolis and passed the following steps during that time:

- The 1950s-1960s

Wartime challenges were reconstruction and industry. Randstad grew via redevelopment, rural-urban migration, and natural expansion. The Dutch government has managed physical development since the 1940s, and for decades, it has managed city expansion to fulfill social, environmental, and economic objectives. These policies support spatial growth. Dutch planners have supported

compact urbanism. Reduce urban and suburban Sprawl, safeguard natural resources, and minimize car usage (Zonneveld & Nadin, 2020). Dutch regional policy favors urban density but simultaneously indicates that national urban and regional strategy avoids consolidating authority in one city. Instead, cities separate functions and authority, creating various economic sectors (Stead & Meijers, 2015). In 1958, a high-level advisory body advised the execution of a plan made during the conflict. Indeed, the war and occupation strengthened the pre-war concept that decentralizing economic activity and combining autonomous communities would produce a safer, wealthier, and equal society, and the so-called Bundled deconcentration or in Dutch, "Gebundelde deconcentratie" emerged in the 1960s (Faludi, 2007). The mentioned high-level advisory body, the working commission, categorized the area as two urban agglomerations (north and south) and suggested green buffer zones.

The Development of the West Country, or so-called in Dutch "De Ontwikkeling van het Westen des Lands" plan, proposed and advocated preserving Green Heart for agriculture core to avoid "sprawl." 1960's "Nota Inzake de Ruimtelijke Ordening in Nederlands," as the first Memorandum on Spatial Planning (National Spatial Planning Report), gave proposals to incentivize enterprises to move to problem regions and decentralize government institutions from the Randstad (Stead & Meijers, 2015). The 1965 Second Memorandum on Spatial Planning, "Tweede Nota over de Ruimtelijke Ordening," shifted population expansion north and south. The Memorandum included Green Heart[18]. Under 'concentrated deconcentration,' four suburbs would expand. This program led to the 1970s

[18] In the 1950s, the Dutch government made a decisive commitment to preserving the intercity spaces within the Randstad region, emphasizing the importance of maintaining these areas as open land. Subsequently, this expansive open space came to be known as the Green Heart. Notably, one of the central principles in Dutch urban planning is the concept of the Green Heart, which delineates the vast expanse within the "Randstad," commonly referred to as the rim city, and its encirclement by various towns and cities (van der Valk & Faludi, 1997).

growth of hubs and new towns (Stead & Meijers, 2015). Figure 23 shows the location of new towns around the Randstad region.

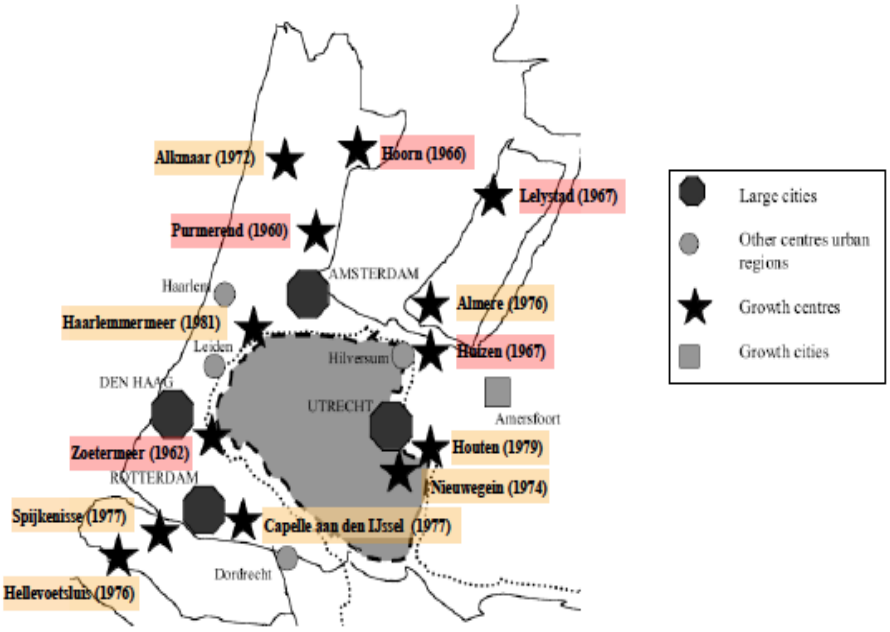


Figure 23 Location of growth centers (and start date) in the Randstad region (Stead & Meijers, 2015)

- The 1970s, 1980s

The 1973 and 1979 oil crises shattered postwar expectations of rapid and sustained economic expansion in the 1970s, causing economic decline and unemployment. Despite rising incomes, which sustained demand for space, this slowed population expansion, urban development, and suburbanization. Recession and slower growth highlighted cities' economic vulnerability and poor quality of life and residential surroundings, leading to population loss (Stead & Meijers, 2015). In the 1980s, macroeconomic conditions and political ideology favoring a more liberal economic approach led to a broad withdrawal of government intervention favoring market-oriented thinking. The third multi-volume national spatial

Strategy, namely the Third Memorandum on Spatial Planning, published in 1973 and modified until 1983, emphasized strengthening urban areas by focusing on urban growth, urban renewal and revitalization of cities, commuting zones, and growth hubs and not Randstad's outskirts, and focused on Urban confinement targeted urban 'bundling' and 'concentration' through the designation and execution of urban growth centers and the supporting public transportation infrastructure to keep them contained inside the city-region (Zonneveld & Nadin, 2020). However, the Green Heart was made development-free. Nevertheless, fears of urban collapse spurred deconcentration in the 1980s. Since the 1960s, decentralization may have caused lengthier vehicle journeys (Bontje, 2021; Stead & Meijers, 2015)

During much of the 1970s and 1980s, the Randstad concept was dormant, not forgotten, but a secondary influence in planning policy for city regions. In the late 1980s, a radical and contentious reimagining of the concept limited its scope to the three main city regions that created a 'West Wing,' with the greatest potential to develop an internationally competitive economic environment. Political opposition ensured that this notion was never implemented in a 1988 draft Fourth Spatial Strategy. The city network was criticized for weakening Randstad and Green Heart's unity and teamwork (Zonneveld & Nadin, 2020).

- The 1990s

1988's Fourth Spatial Planning Memorandum proposed "compact cities." The Strategy aimed to stop urban outflows of people and jobs, encourage urban growth, and densify suburbs. The Fourth Memorandum required public transport and vehicle access for certain jobs. The Fourth Memorandum highlighted Randstad's international competitiveness compared to other Northwest European urban centers. The Green Heart and buffer zones between cities were distinctive assets of Randstad's decentralized system. Decentralization increased infrastructure needs. In the early 1990s, the compact city idea was broadened. The

idea that Randstad was vital to the Netherlands' economic competitiveness continued (Bontje, 2021) in a supplemental report to the Fourth Memorandum on Spatial Planning, "Vierde Nota over de Ruimtelijke Ordening" extra was termed "Vinex"), driving urban growth inside cities or near existing cities to avoid long-distance travel. Figure 24 depicts the Metropolitan networks in the Fifth Memorandum on Spatial Planning.

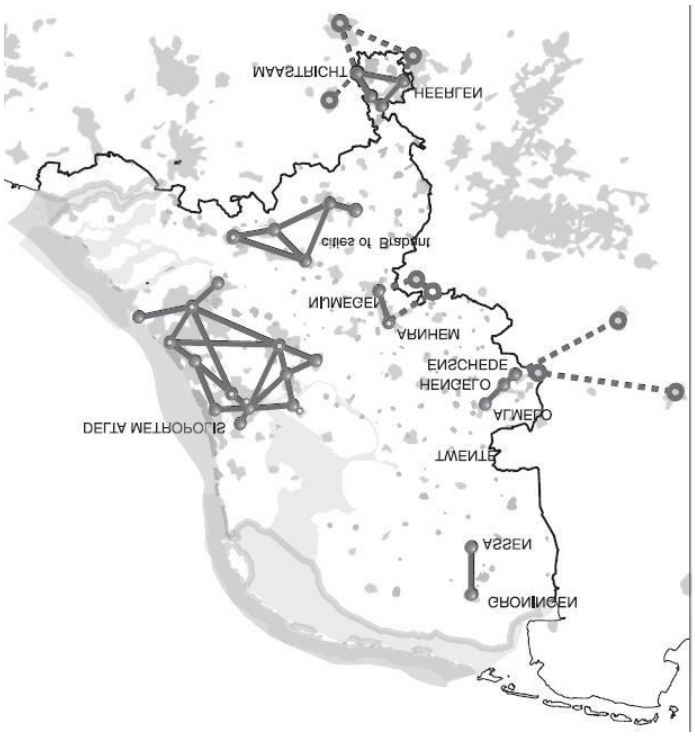


Figure 24 Metropolitan networks identified in the fifth memorandum on spatial planning

Before public transit was established, many trips were taken by alternative means, which was difficult to reverse (Stead & Meijers, 2015). After VINEX, residential and commercial buildings near city limits grew, notably along highways and access roads. 2000-2006 saw 60 km2 of commercial and industrial growth. Van Eck et al. Insufficient public transit causes traffic and pollution. Late 1990s planning emphasized Randstad's networked urban areas. Randstad's integrated urban network and huge metropolitan system led to the 'network city' Amsterdam, Utrecht, and South Wing being honored (The Hague and Rotterdam). Network

cities aim to expand and reinforce urban networks via new construction and infrastructure. Fifth Memorandum on Spatial Planning (2001) focused on Randstad's network city approach. Dutch metropolitan networks include Randstad (Zonneveld & Nadin, 2020).

- The 2000s: Rescale

In the 2000s, Dutch neoliberalism decentralized, outsourced, or abandoned federal government functions. Also, reduced EU public expenditure allowed the private sector to take over government tasks. Local government and northwest Europe transnationalized spatial planning. The 2006 National Planning Strategy changed the planning language. The government no longer decides what to build. This paragraph is disorganized. The Strategy recommended building along transportation routes to minimize congestion and boost economic performance. National Planning Strategy included urban networks. Regional and municipal governments are empowered under the 2008 Spatial Planning Act. The 2012 National Structural Vision guides local urbanization planning. The national government agrees on urbanization programming with municipal and regional authorities in Randstad's surrounding major transit hubs. Urban buffer zones and density are gone. Decentralized planning has slowed urban growth. Economic and demographic declines also contribute—liberalization and decentralization of urban planning boost 'agglomeration economies' (achieved in larger urban systems). Despite growth limits, urban periphery shopping has flourished. Britain rejects out-of-town retail zones. Local and regional authorities have increased decision-making because of the Spatial Planning Act (Bontje, 2021; Stead & Meijers, 2015).

Randstad overlooked strategic interrelationships to focus on city regions and changed to ICT and creative industries (Bontje et al., 2011). Delft and Amsterdam's universities filled Randstad's policy gap. The group envisioned an internationally competitive, functionally integrated polycentric city beyond

Randstad. Four Randstad planning councilors declared Deltametropolis-scale spatial planning and activities government policy (Deltametropool, 1998; Zonneveld & Nadin, 2020). The government revised Delta's spatial policy. The Randstad was re-established as the major site for Dutch government-supported economic drivers: three dominant economic centers (of 13), nationally important development projects or zones like Schiphol Airport and the port of Rotterdam, and agricultural complexes or Greenport (Bontje, 2021)

- 2010's since today

From 2007-2009, economic growth in the Netherlands averaged 4.5% annually. The "Great Recession" was caused by international and domestic factors, and the coalition of 2010 was neoliberal. Since June 2012, Spatial Vision on Infrastructure and Spatial Planning or SVIR[19], has been operational. This policy guides government spending and infrastructure planning. The SVIR establishes national objectives that all government entities (ministry branches) must achieve. The current administration disregarded the Randstad model for spatial development in the 2010s in favor of SVIR (2012). The importance of spatial planning has diminished since the ministry was abolished (in 2017, spatial planning moved again to another ministry). A new Environment Planning Act, or "Omgevingswet" in Dutch, was enacted in 2012. It incorporates fifteen statutes and all of the government's environmental initiatives. The National Environmental Planning Approach (NOVI) launched a "streamlined" approach in 2019 to include sectoral environmental criteria into global "environmental" law and policy. The Act, however, will not go into effect until 2022, a full decade after it was passed. The idea and design of NOVI are similar to those of other National Geographic projects. As its position weakens, the federal government must rely increasingly on state and regional governments, agencies, corporations, and civil society. Topics include theories and regulations. New provincial, municipal, and agency

[19] Structuurvisie Infrastructuur en Ruimte

instruments are necessary to achieve NOVI's conflicting goals. Randstad has lauded Green Heart for being easily accessible. Community "complementarity" is a top priority for NOVI (Bontje, 2021; Zonneveld & Nadin, 2020).

4.3.3 Mobility system and structure of Randstad

The Netherlands' transportation system is rated the fourth most competitive in the world in the Global Competitiveness Report 2014-2015 (Bontje, 2021; Stead & Meijers, 2015). Commerce and logistics are vital to Randstad's and the country's success. Cities like Rotterdam's port and Amsterdam's Schiphol Airport are in this area. This area's prominence as a hub has contributed to the rise of the Randstad economy and the region's popularity with foreign companies. Seventy-five percent of Dutch exports and sixty percent of FDI go there (OECD 2007). The total length of roads in the Netherlands is 139,295 kilometers. Both the train and bike infrastructure in the country is quite well developed. Automobiles account for 75% of passenger transit's 200 billion annual kilometers. Half of all trips in the Netherlands are taken by car, 25% by bike, 20% on foot, and 5% by public transportation. There were 58 million arrivals and departures at Dutch airports in 2013. One hour daily is generally needed for a 30-kilometer walk (Stead & Meijers, 2015).

The Rhine and Meuse rivers link Rotterdam to European countries like Germany, Switzerland, and France. The Netherlands is a major transportation hub, transporting 40% of all EU containers and 2/3 of all inland water cargo. The Dutch transportation and shipping industry moved 1.65 billion tons in 2010. The Netherlands also relied on pipelines (36%) and rail (2%). Most Dutch people who work outside their homes commute (although there is a considerable amount of commuting between Amsterdam and Utrecht and between The Hague and Rotterdam). Especially inside the Randstad, transportation between municipalities has barely increased in the past few decades (CBS 2006). The demographic shifts

among professionals have boosted the Randstad commute (Burger et al., 2014; Stead & Meijers, 2015).

- Roads for transportation

The Netherlands has more public roads than Germany and France but less than Belgium. The Netherlands has 2,758 Kilometers of roadways or 64 Kilometers per 1,000 square kilometers. The Netherlands has a lower rate of vehicle ownership than its neighbors and Europe. Freight accounts for 20% of all transportation (Stead & Meijers, 2015).

- Facilities for cycling

In the Randstad area of the Netherlands, bicycling has become an increasingly common mode of transportation. Most Dutch families have many bicycles, and everyone in the country has at least one. About one-third of the population of the Netherlands commutes mostly by bicycle. About 25% of all trips are taken on bicycles. Bicycles carry almost as many people as trains do in the Netherlands. Both the Netherlands and Denmark were recognized as among the most bike-friendly countries in Europe by the European Cyclists' Federation in 2013. The facilities for bicyclists are clean, well-lit, and designated. There are around 35,000 kilometers of dedicated bike lanes on major roads. Most major intersections have special bike lanes or traffic lights designed for cyclists to ensure their safety at these intersections. Central business districts and train stations typically have many bike racks (Stead & Meijers, 2015)

- Rail System

Rail transit is prominent in the Netherlands. The rail network spans 3,013 route kilometers and 6,830 kilometers of electrified track. The passenger-focused network links the vast majority of Dutch cities. The nation's rail network is managed by ProRail company, while separate businesses are responsible for train

operations. The Dutch Railroads move people (Nederlandse Spoorwegen, or NS). There are service providers who give fewer features (Arriva, Syntus, Connexxion, Breng, DB Regio, NMBS, Veolia and DB Regionalbahn Westfalen). During the week, most train stations are serviced every hour and a half. Two to four trains each hour go along a sizable network section. Eight trains will pass you on crowded lines every hour (most of Randstad). In the EU, Dutch railways convey one million people per kilometer. Four prominent train stations in the Netherlands have been restored (Amsterdam, Rotterdam, The Hague, and Utrecht). Rotterdam Central was rebuilt in March 2014, and three more stations are planned. The 3,013 kilometers of track in the Netherlands are used by high-speed trains. Holland, Belgium, and France are all linked by the South High-Speed Line, which runs from Amsterdam to Schiphol Airport, Rotterdam, Antwerp, Brussels, and France (including Paris and Lille). The first public operations followed a year later, in 2009. The line cuts down on the time it takes to get between Rotterdam and Amsterdam by about 20%. Standard rail tickets are valid on the high-speed trains between Amsterdam and Schiphol, Rotterdam and Breda. The service was poorly welcomed (Gil & Read, 2012; Stead & Meijers, 2015).

- Other public transit

Public transportation is operated by the city governments of Amsterdam, Rotterdam, and The Hague, while these services are outsourced in the remaining areas of the Netherlands. Few people take buses for long distances. Buses travel to and from the smaller towns. The cities of Amsterdam and Rotterdam are serviced by metro and tram networks, while The Hague is served by a tram network and the Rotterdam-The Hague light rail (RandstadRail) (Gil & Read, 2012).

4.3.4 Policies for the management of transport infrastructures

In recent decades, the Dutch government has taken numerous steps to strengthen the country's hub status and ease of access. Recent examples of Randstad's

infrastructure developments include airport landing and handling capacity expansions at Amsterdam's Schiphol (Polderbaan and Pier A) and the High-Speed Line South (HSL-Zuid). Infrastructure policy became the sole determinant of Randstad's growth in metropolitan areas nearly ten years ago. There is less enthusiasm for housing policy reform and new construction. Regarding policy, the government is more interested in those who live in major metropolitan areas. Some new residential developments have even cropped up amid previously uninhabited environments. The building of homes, businesses, and other urban infrastructure has slowed dramatically due to the economic downturn. In June 2012, the country's national policy included the Strategic Vision for Infrastructure and Spatial Planning (SVIR). This document serves as a policy roadmap for the government's investment program and an overarching strategic plan for physical space management. The SVIR establishes laws that Congress must implement (various ministerial departments and government agencies).

One governmental instrument created to integrate better national spending on planning and development, transportation, and other aspects of quality of life is the Multi-Year Plan for Infrastructure, Spatial Planning, and Transport (MIRT). To get government funding, many prerequisites must be met, all spelled out by the MIRT standards. Every year, leaders from all levels of government get together to debate how to advance a shared agenda. Thus, MIRT contributes to regional priorities by offering a structure within which long-term investments in infrastructure can be made. Randstad's operations aim, in part, to make its services more easily accessible (Gil & Read, 2012; Stead & Meijers, 2015).

The proposed TOD[20] of Stedenbaan is located in southern Randstad, along the train line between The Hague and Rotterdam and on to Dordrecht. This expansion has been made partly by the High-Speed Line South's intercity train services, which have freed up track space for more local and regional railway lines.

[20] Transit-oriented development

The area around the stations will be used for various things, including homes, offices, hotels, conference centers, shopping, bus terminals, parking lots for automobiles and bicycles, and the redesign of public spaces. The long-term objective of the plan is to boost rail passengers while also enhancing the nodal value of station areas and the quality of life in the surrounding communities (Spaans & Stead, forthcoming). Moreover, the concept largely depends on introducing metro-style, high-frequency services with minimal inter-train delays (Gil & Read, 2012; Stead & Meijers, 2015). The Dutch government has been discussing road pricing to reduce traffic congestion for some time. During rush hours and on congested routes, the most polluting vehicles were supposed to pay a premium. There was a lack of political will and an imminent economic catastrophe, so the program was put on hold a few years ago. Unlike many monocentric metropolitan regions, Randstad has never had a unified system of public transit connections because municipal governments are more powerful than regional administrations, and local needs are often prioritized above transportation development. The Randstad differs from monocentric zones in that it does not have a single center around which everything else revolves. Therefore, the public transit networks in Randstad are not as well connected as they may be (Burger et al., 2014; OECD, 2007). Without a hitch, the system can process and transmit requests and data. People can ride the bus, train, or subway anywhere in the country using a single chip card. They can also get comprehensive public transportation data online, including door-to-door planning and real-time route information (Stead & Meijers, 2015).

4.4 Summary of lessons learned from three polycentric regions as learning fields

Based on the insights presented in the preceding sections, valuable lessons can be drawn from the experiences of the three learning field situations as they relate to the management and planning of polycentric city regions, which are stated below.

4.4.1 Lessons from the German planning system

From the discussion about the German planning system following points and lessons can be learned:

- Germany is a democratic, social, federal state with a central government (Bund) and constituent states (Länder), and each federal state (Land) has its constitution and council responsible for planning issues. It shows the level of interdependence at the planning level in Germany and the same central Government. The federal spatial planning law (ROG) regulates the states' rights and obligations for spatial development and regional planning.

- Planning in Germany is delegated to municipalities, which are guided by the "Baugesetzbuch" (Building Code) and create land-use plans and development plans.

- The German planning system follows the opposing influence principle (Gegenstromprinzip), balancing responsibility between federal, state, regional, and municipal planning layers.

- Planning stages and tools can vary among federal states based on topography, population density, history, and planning culture.

- Germany has 104 planning regions, with different planning competencies assigned to local associations and state-defined regional planning areas, which self-shows particular attention to the local situation in planning. For instance, the Ruhr Polycentric region in North Rhine-Westphalia has its state planning law and planning regions managed by regional councils and the same manner applied to the Stuttgart regions, which follows a special mandate for the region.

- German planning documents focus on developing future-oriented spatial planning guidelines for metropolitan regions, with efforts to improve connectivity, promote cooperation, and boost urban systems.

- Regional cooperation requires functional interconnections and links, and mapping these linkages is important for strategic action and regional cooperation.

4.4.2 Lessons from German public transport system

The following lessons about public transport management in the Ruhr region and Germany can be learned:

- Germany has a system of Verkehrsverbund, which refers to cooperative alliances for integrated public transport services within a defined transport area. It involves collaboration between carriers and local administrations to provide an integrated transport network and facilitate easier access to public transport.

- Collaboration models: Different collaboration models exist within Verkehrsverbund, depending on the level of subsystem interconnection and the region's spatial and geographical organization. These models range from coordination in specific subareas to comprehensive organizations with extensive contractual agreements, responsible for setting fares, organizing networks and timetables, and improving overall public transport systems.

- Integration and coordination: The establishment of Verkehrsverbund aimed to integrate public transportation systems and eliminate competing services, leading to more efficient coordination and increased demand for public transport. The coordination includes interlinking various transport modes, such as buses, trams, and subways, and introducing combined timetables and tickets.

- Regionalization and governance: The regionalization of public transport in Germany led to the restructuring of Verkehrsverbund organizations, involving a shift from transport companies to local authorities. The Verkehrsverbund Rhein-Ruhr (VRR) is an example of a large European transport association operating at political, management, and operational levels.

- Financing and relationships: Municipalities in the Verkehrsverbund are responsible for providing appropriate public road passenger transport and often finance their own local transport companies. The relationships between municipalities, the Verkehrsverbund, and transport companies can be complex, involving legal obligations and financial considerations.

- Importance of "Verkehrsverbund": Verkehrsverbund has gained significance in Germany, covering a significant portion of the population and serving as the primary provider of transport services. It has led to

increased quantity and quality of services, rising passenger levels, and stable or increasing public transport usage, even in the face of rising car ownership rates.

- Flexibility and adaptability: The Verkehrsverbund model has shown flexibility and adaptability, catering to both polycentric regions like Rhine-Ruhr and monocentric regions like Berlin and Hamburg. The model can be applied in various regional and local contexts, allowing for the preparation of integrated public transport services.

These lessons highlight the benefits of collaborative approaches, integrated networks, and coordinated efforts in public transport management to improve accessibility, efficiency, and sustainability.

4.4.3 Lessons from regional green belt

The context of the green belt planning and its experiences in Germany reflect the following lessons:

- Importance of regional green belts: Regional green belts play a significant role in protecting open space from uncontrolled land consumption and development. They are beneficial in preserving open space in metropolitan areas and contribute to reducing land usage.

- Benefits of regional green belts: Regional green belts provide ecological functions, recreational areas, and protection for agricultural and forested zones. They promote air quality, provide leisure opportunities, and preserve water-generating regions.

- Historical development of regional green belts: Regional green belts were first developed in German spatial planning in the 1960s, with the term being used in the Ruhr polycentric region, regional development plan in

the 1970s. They have since become an integral part of regional planning in the Ruhr region.

- Role of "Siedlungsverband Ruhrkohlenbezirk" (SVR): SVR played a significant role in setting and describing regional green belts in the Ruhr Region. The SVR Planning Atlas in 1960 marked a milestone in planning and open space protection in the area.

- Green belt impact on urban development: Green belts in Germany, including the Ruhr region, control the physical development of urban areas. They act as a control zone for spatial growth, guiding the expansion of central cities and suburbs while preserving open space.

- Varied planning approaches: German greenbelt planning differs from practices in other countries, as there are few legal standards or government directives. This leads to variations in greenbelt coverage and land-use consolidation.

- Future considerations: Future regional plans in the Ruhr region are considering new delineations of green belts. Expansion of green belt areas is being explored, especially in less densely populated outlying zones.

- The adaptive decline in the inner Ruhr area: The inner Ruhr area, where the original regional green belts are located, may experience an "adaptive" decline, reducing the transformation of open space to urban or non-open space land cover.

Overall, it can be said that regional green belts protect open space, their historical development in Germany and the Ruhr region, and the ongoing efforts to maintain and expand these green areas for ecological, recreational, and urban planning purposes.

4.4.4 Lessons from the case of Stuttgart

From the learning field of Stuttgart, several instructive lessons can be gleaned, including:

- Benefits of polycentric city-region spatial organization: The polycentric organization in the Stuttgart region has led to advantages such as shorter travel times and cheaper transportation costs for commuters. This highlights the benefits of dispersing economic and residential activities across multiple regional centers.

- Importance of comprehensive management and planning: Managing and planning for a polycentric region requires a united voice and umbrella organization. The creation of the Association of the Stuttgart Region (VRS) demonstrates the need for a comprehensive management approach to effectively address the diverse features and challenges of a polycentric region.

- Innovative governance structures: The VRS is an example of innovative governance structures and organizations. It establishes a two-tier regional planning and management system with public planning enterprises and the Neckar Regional Association. This demonstrates the importance of developing flexible and adaptive governance structures to address the complex needs of a polycentric region.

- Responsibilities of regional planning organizations: The VRS and the Regional Association Stuttgart have various responsibilities related to regional planning, including regional open space framework, environment planning, transportation infrastructure, public transport planning, waste management, economic development, and tourism marketing. This highlights the broad responsibilities that regional planning organizations

may have in managing and coordinating activities within a polycentric region.

- Role of regional transportation planning: The VRS is involved in regional transport planning and operates Stuttgart's regional public transportation systems. This underscores the significance of efficient and well-coordinated transportation systems in supporting the functioning of a polycentric region and improving connectivity for residents and commuters.

4.4.5 Lessons from the case of the Ruhr Region

Development and regional planning have a historical background in the Ruhr area, which can be said initially founded with the establishment of the first planning approach in 1912. This teaches us the importance of understanding the historical context and the evolution of planning processes in a region:

- The Regionalverband Ruhr (RVR) is an important planning body in the Ruhr Region for coordinating the planning and management of the polycentric region of Ruhr with its four districts and eleven cities that plan and work together. They all form the metropolis Ruhr, one of the largest conurbations in Europe. The RVR has been involved in regional restoration, development plans, and brownfield rehabilitation.

- Voluntary municipal corporation: The First steps to collaborate with common concerns of the close cities started with the voluntary municipal corporation. The idea of a voluntary municipal corporation with restricted control and functions, as pursued by Robert Schmidt, a key municipal official of the city of Essen, demonstrates the value of partnership and collaboration among local governments. It shows that a cooperative approach can be effective in addressing regional challenges, and such values and steps find themselves in a Legal basis for regional planning by

the creation of the SVR (Ruhr Coal Regional District) in 1920, based on law, emphasizes the importance of having a legal framework to support regional planning efforts. This lesson highlights the need for clear legal mandates and responsibilities for "regional planning organizations" which will work as an umbrella unity for different stakeholders. Here are different cities with different interests and competitions.

- Adaptation to changing circumstances: Despite declining coal and steel production, the SVR remained an active planning body by shifting its focus to urban restoration and development plans. This demonstrates the importance of adaptability and resilience in regional planning, especially during economic changes.

- Regional development planning: The SVR's production of a regional development plan in 1966 showcases the significance of long-term strategic planning for regional development. It highlights the need for comprehensive plans considering various regional growth and sustainability aspects.

- Top-down and bottom-up collaboration: The text mentions the IBA International Building Exhibition and the collaboration between municipalities in brownfield rehabilitation projects. This illustrates the benefits of top-down financial steering and quality management by the state and informal planning instruments for bottom-up cooperation. The lesson is that combining top-down and bottom-up approaches can foster effective collaborative regional planning governance.

- Stimulating cooperation: The reference to regionalizing procedures in North Rhine-Westphalia state teaches us the importance of implementing measures to stimulate and improve cooperation at the regional level. This highlights the need for ongoing efforts to foster collaboration among regional stakeholders and promote joint projects and initiatives.

4.4.6 Lessons of the case of Randstad

From the case of Randstad of Netherland, the following lessons can be learnt:

- Polycentricity: Randstad is planned as a polycentric city, with multiple urban centers surrounded by a rural Green Heart. The current situation of the region shows polycentricity in urban planning can help distribute economic activity and create a more balanced and sustainable urban system.

- Decentralization and deconcentration: Randstad has experienced decentralization and deconcentration efforts to alleviate urban pressures and promote economic growth in different regions. The decentralization of economic activity and the combination of autonomous communities were seen as strategies to create a safer, wealthier, and more equal society. It shows, Decentralization and deconcentration with purpose of focusing on the local and regional capacities, can help balance economic development, reduce congestion, and enhance regional competitiveness.

- Urban networks and interconnectivity: The concept of a network city has been emphasized in Randstad's development, aiming to expand and reinforce urban networks through new construction and infrastructure. The integration of different cities within a network can enhance their collective competitiveness, and from the mentioned points, can be considered, fostering urban networks, and improving interconnectivity between cities can boost economic growth and collaboration.

- Transportation and mobility: The Netherlands has a well-developed transportation system, with efficient road networks, a strong focus on cycling infrastructure, and important hubs such as Rotterdam's port and Amsterdam's Schiphol airport. From the case of Randstad, it can be learned that investing in transportation infrastructure, promoting

sustainable modes of transportation like cycling, and establishing key transportation hubs can enhance regional connectivity and support economic activities.

- Economic competitiveness: Randstad has been recognized for its international competitiveness, attracting foreign companies, and playing a significant role in the country's economy, and it shows creating an environment that fosters economic competitiveness through specialization in different sectors, attracting investments, and leveraging key assets can contribute to regional development and prosperity.

- Government involvement and planning: The role of government in spatial planning and urban development has evolved, with shifts towards decentralization, market-oriented thinking, and empowering regional and municipal governments. Considering this matter, it can be concluded that government involvement and planning play a crucial role in shaping urban development, managing growth, and achieving sustainable outcomes. Moreover, in any case, from the Top-Down or Button-Up approaches, the Government plays a critical role in the development process of a region.

In general, it can be said that according to the experiences of Germany and the Netherlands in the planning process, it is very important to pay special attention to regional and local capacities in the planning process. Also, avoiding a top-down view, using a single tool and a single structure in planning, delegating authority to regions, and avoiding centralization will lead to favorable results in urban and regional planning.

The first step towards achieving the goals of planning and sustainable development in a Polycentric region is to establish cooperation between cities in a polycentric region with emphasis on common motives, and this should be done from the very beginning small steps.

To develop a framework that emphasizes the common challenges of a polycentric region, the central government needs to create an entity with broad authority at the regional level and offer the appropriate legal tools to facilitate collaboration amongst cities. Additionally, it is necessary for regional planning and management. It might assist in achieving the objectives of sustainable development.

To avoid competition and interference between cities in the area, this institution should also consider the three major regional challenges of waste management, environmental management, and public transportation. It should do this by establishing a protective umbrella and taking on executive authority in the abovementioned cases.

Urban neighborhoods in polycentric configurations can manage physical development and urban sprawl while preserving the area's ecological capacity by utilizing the green belt means. The past experiences of the Ruhr Region, Stuttgart, and Randstad in the Netherlands are used to demonstrate this importance.

Creating a platform for cooperation in integrating the organization of public transportation with a focus on rail and multi-modal transportation has, as noted in all three European cases, led to beneficial outcomes in the field of public transportation. To achieve long-term development in a polycentric region, it is required to pay special attention to integrating public transportation management, planning, and operation.

5 Mazandaran as the case study and its adaptation to the polycentric city-region structure

Recent research has revealed that, in addition to functioning polycentric city-region s in Europe, polycentric urban regions appear to be emerging in developing countries such as China (H. Cheng & Shaw, 2018; Liu & Wang, 2016), Turkey (GeoScape & 2018, 2018), Singapore (Han, 2005), and Iran (Dadashpoor & Saeidi Shirvan, 2019; Dadashpoor & Salarian, 2015a). Polycentric city-regions emerge when previously adjacent but separate cities merge to form a more comprehensive city region. As a result, regions identified by interdependent economies, collective labor markets, common infrastructures, and various binding settlements are increasingly being combined into overarching entities(Liu et al., 2018). It is also claimed that the polycentric city-region is one of the insignificant emerging urban patterns (Wang et al., 2019). Polycentric city-regions have been accepted as an ideal-typical spatial organization for measuring urbanization processes and are increasingly being 'interpreted' into a policy framework (Münter et al., 2020; Park et al., 2020b; Wang et al., 2019).

Though it has its formal origins in the European context (as a legal document), polycentricity was developed in this region's methodological and practical implications (Dadashpoor et al., 2018; Dadashpoor & Saeidi Shirvan, 2019; Münter & Volgmann, 2021). In developing countries, EU planning and governance experiences guide the transition from a monocentric region to a polycentric one to achieve the desired function (Dadashpoor et al., 2018). Studies in developing nations such as Iran examine the feasibility of transforming or shaping polycentric spatial structures for certain urban regions, including the Mazandaran province of Iran (Farnam, 2020; Shahmiri & Nikbakht, 2016). However, according to (Haqjou, 2015), the Mazandaran region differed from other polycentric cases in the Middle East and Iran. He explained that

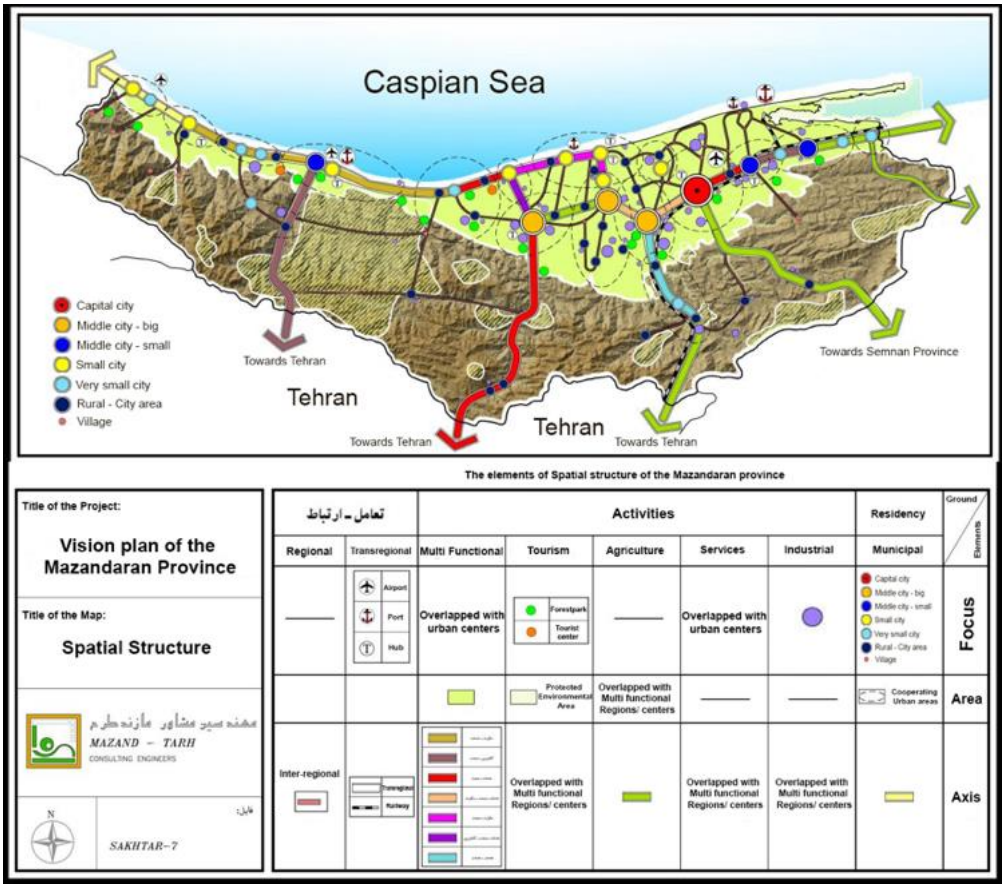
the interactions of various cultural, geographical, and political trends shaped the polycentric spatial organization of this region.

As a result, the Mazandaran region was chosen as a case study in this research to cover a gap in knowledge in the field of Sustainable development assessment in a polycentric city-region in developing nations, with a focus on the mobility aspect of the polycentric city-region.

5.1 Mazandaran region

Mazandaran is a densely populated province with many natural resources. It's a classic polycentric area in the Middle East and Iran's dense green belt (Mazandtarh Consulting Engineers, 2010c). Plains, prairies, forests, and rainforests stretch from the Caspian Sea to the rugged Alborz Sierra, which includes Mount Damavand, one of Asia's highest peaks and volcanoes. Sari governs Mazandaran's 22 counties. According to the most recent national census of 2016, the province's population was 3,283,582 (Statistical Center of Iran, 2016). People from all over Iran visit the province, which hosts about 15 million tourists annually.

Map 2 Red area is the location of the Mazandaran province in Iran (Source: Author)



Map 3 Spatial structure of the transportation corridors of the Mazandaran region

5.2 Mazandaran and polycentric spatial structure

5.2.1 Morphological polycentricity of Mazandaran

In order to deal with the concept of the polycentricity of Mazandaran, it is necessary to recognize and adapt Mazandaran province's spatial structure using the previously described polycentric city-region model. This province's polycentricity has been considered in scientific and planning documents, including efforts of Haqjou (Haqjou, 2018), Mazandtarh Consulting Engineers (Mazandtarh Consulting Engineers, 2010c), Moshfeghi (Moshfeghi & Rafiyan, 2014).

Accordingly, Haqjou (Haqjou, 2015) undertook a substantial endeavor to ascertain the fundamental elements for assessing the polycentric configuration of the Mazandaran

province. Haqjou conducted a comprehensive analysis of the spatial arrangement of Mazandaran, employing a morphological polycentricity framework. The scope of this study encompassed the time frame spanning from 1976 to 2013.

The study findings indicated that Mazandaran demonstrated a high level of adaptability, efficiently optimizing each indicator and successfully aligning its regional organization with a polycentric structure. The study's findings were derived through the utilization of the most suitable index framework for each indication. Concerning the morphological polycentricity of Mazandaran, Haqjou concludes that the province exhibits several crucial conditions for adopting a polycentric structure. As a result, Mazandaran is progressing toward the status of a developed polycentric city-region.

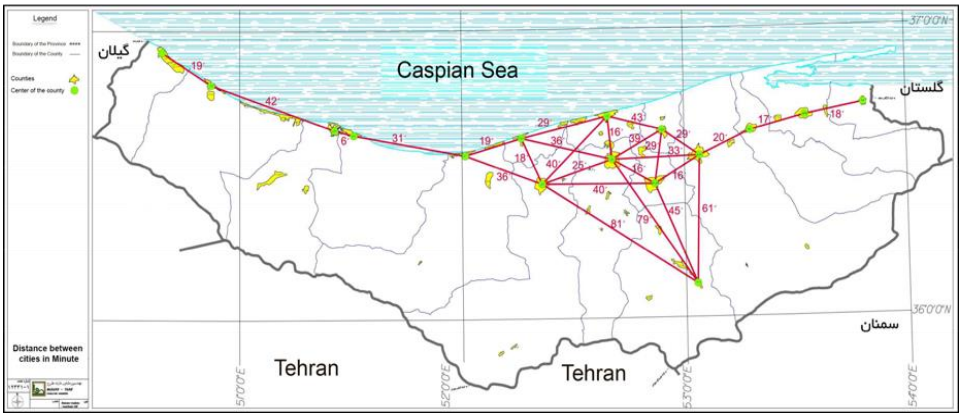
In another study, Mazandtarh Consulting-Engineers (Mazandtarh Consulting Engineers, 2010c) evaluated province polycentricity in terms of the functional relationship of the elements using the spatial structure criteria of the polycentric city-region, such as Travel-Time-Index, Bond-Strength-Index, and Green-Polycentricity-Index.

- **The travel time index in Mazandaran**[21]

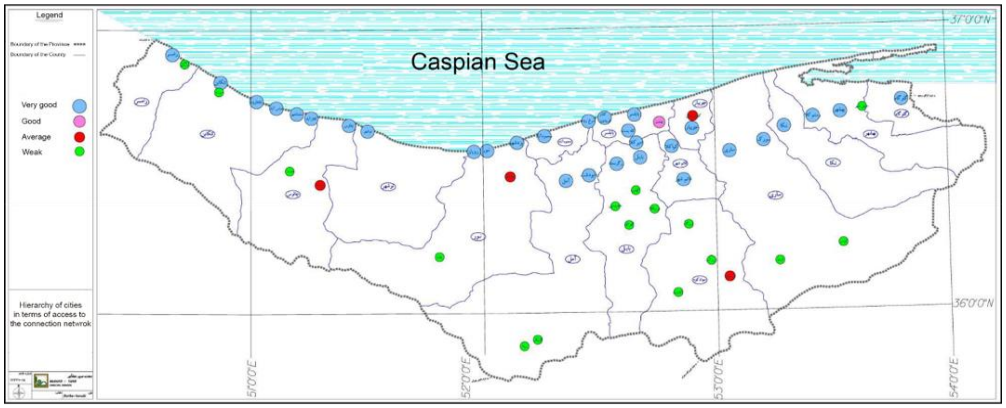
Map 4 illustrates the results of the evaluation of the Mazandaran vision plan. The spatial organization of settlement centers within the Mazandaran city-region aligns with the three proposed travel time categories, validating that this spatial structure adheres to the polycentric city-region pattern, particularly for the province's major urban centers. In Map 5, Mazandtarh Consulting Engineers (Mazandtarh Consulting

[21] The travel time index is considered as one of the criteria for measuring reciprocal relations between centers. On the small scale of this index, the most used time intervals shown for the neighborhoods of the two cities so that daily reciprocal relations can be achieved. In this regard, Geds (1915), described average one-hour is a reasonable distance between neighborhoods. Later, Hans Bloomenfeld (1971) set the distance to be less than 40 minutes. David Button (1955) also found the time to be less than 30 minutes to one hour is proper distance time between two centers.

Engineers, 2010c) also mapped the mobility and connectivity quality and the hierarchy of Mazandaran cities and settlement centers.



Map 4 Travel time between Mazandaran settlements centers in minutes



Map 5 Mobility and polycentric hierarchy of cities in Mazandaran

- **The bonding strength in Mazandaran**

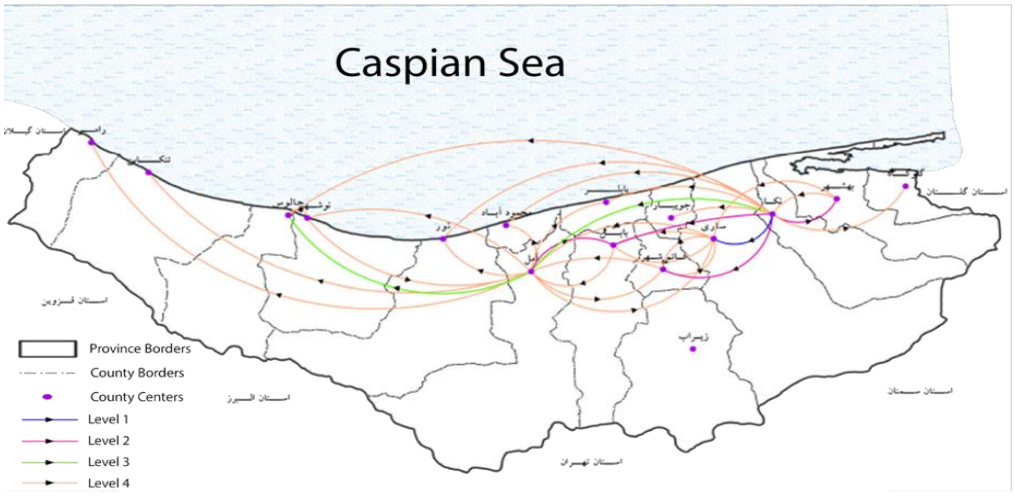
The bonding strength shows showing level of bonding and relationship between urban centers in polycentric city-regions (Zebardast & Ardavani, 2021). Assessment of Bonding Strength inside the city-region in Mazandaran is discussed in Haqjou's (Haqjou, 2018) endeavor to determine how much this city-region spatial structure

follows the polycentric city-region patterns. As a result, practical data availability methods were used to evaluate this index. In addition, he argues that physical relationships develop due to spatial proximity and that the phenomenon of spatial proximity in the metropolitan area of Mazandaran can be analyzed using the average physical distance between cities. Thus, the Bonding Strength (via distances between urban centers) for evaluating the Mazandaran city region's functional relationship was investigated in the western, central, and eastern parts of the province. In the following, the bonding strength of Mazandaran cities is calculated by Mazandtarh Consulting-Engineers in the Mazandaran Vision plan (Mazandtarh Consulting Engineers, 2010c) and reveals that the region's west bank has the strongest bonding power in terms of the distance between urban centers and the capacity of their route.

- **Green index in Mazandaran**[22]

In order to evaluate the Green index, (Moshfeghi & Rafiyan, 2014) looked into four flows in the province of Mazandaran: people, goods, capital, and information. Each inbound and outgoing flow in the people and commodity functions is categorized using graphs. The Green polycentric Index in measuring the functional relationships of Mazandaran province was 0.56, indicating that the intensity of the reciprocal functional relationships between the Mazandaran city-region's centers is firmly strong, given that the maximum amount of this Index for a polycentric city-region is defined as 0.25. In Mazandaran, it also shows a significant share of network polycentric performance intensity.

[22] This index quantifies the relationships between urban nodes using network analysis theories. The Green polycentrity index, using daily flows and considers the degree of nodes as the centrality of each node, thereby defining the distribution of centralities within the region.



Map 6 Flows of goods inside Mazandaran region county centers (Moshfeghi & Rafiyan, 2014)

Expanding upon the preceding discussion and insights drawn from a range of studies, the comprehensive exploration of Mazandaran's Polycentricity, incorporating both the Functional and Morphological Criteria of Polycentric city-regions, yields substantial findings. It is evident that the Mazandaran province leans towards a polycentric spatial arrangement, deviating from monocentric structures and distinctly displaying a stronger inclination towards polycentric over monocentric. Nonetheless, it is crucial to underscore that while adopting a polycentric spatial configuration, the Mazandaran city-region is progressively advancing toward the status of a developed polycentric city-region.

5.3 Sustainable development in Mazandaran polycentric city-region

To present a comprehensive analysis of sustainable development in Mazandaran province, drawing upon previous research studies conducted by Sheikh Azami and Divsalar (Sheikh Azami & Divsalar, 2015). The research aimed to investigate and describe the sustainable development situation in the province. Sheikh Azami & Divsalar (Sheikh Azami & Divsalar, 2015) utilized a separation point model, which considered economic thresholds and commercial borders, to determine the geometric characteristics of Mazandaran province's urban network. Furthermore, they applied

the combined development index as a metric for assessing sustainable urban development, ultimately determining the level of development within network communities. The research encompassed 51 towns and cities in Mazandaran, specifically focusing on the 21 capital cities.

Sheikh Azami & Divsalar (Sheikh Azami & Divsalar, 2015) used a broad range of sustainable development variables that considered social, economic, and environmental factors. These factors were used to calculate the "Human Development Composite Index" and determine the degree of development in different regions (cities) of the province of Mazandaran. The relationships between these variables were examined within this analytical framework, shedding light on their combined impact on sustainable urban development. The analysis of correlation coefficients revealed the disparities in development-rates across the province of Mazandaran, allowing for identifying indicators that significantly contribute to sustainable urban development. Table 3 shows the level of development of Mazandaran cities according to Sheikh Azami & Divsalar (Sheikh Azami & Divsalar, 2015) study result.

Level of Development	Counties/ Cities	Numbers	Percentage
Developed	Ramsar, Chalos, Sari	3	14.28
Intermediate developed	Amol, Babol, Babolsar, Farbodunkanar, Tankabon, Abbasabad and Nowshehr	7	33.33
Low middle developed	Swadkoh, Swadkoh North, Qaemshahr, Simorgh, Noor	5	23.8
underdeveloped	Behshahr, Joibar, Mahmudabad, Neka	4	19.04
Deprived	Gulogah, Miandorud	2	9.52

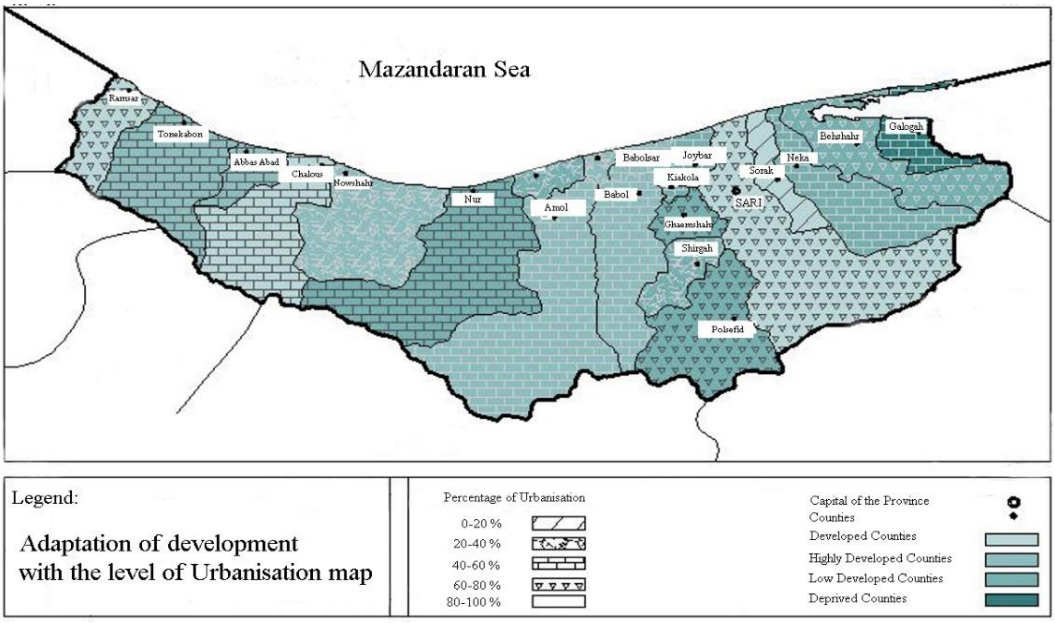
Table 3 Level of development of Mazandaran cities according to the "Human Development Composite Index" (Sheikh Azami & Divsalar, 2015)

The spatial configuration of Mazandaran province highlights a distinctive pattern where cities are arranged along two primary horizontal and sectoral axes, extending from east to west and north to south, with Sari as the focal point. The research findings, as depicted in table 1 (see page 38), vividly illustrate disparities in sustainable urban development across the cities within Mazandaran province. Notably, a substantial portion of cities located to the west of the province, particularly those interconnected through the province's linear urban network stemming from its capital, Sari, exhibit a notably elevated level of development. Conversely, cities that manifest signs of underdevelopment and deprivation are predominantly within the province's sectoral urban network.

Within the spectrum of the province's seven Intermediate developed cities, a mere two cities—Amol and Babol—are integrated into the sectoral urban network of the province. Conversely, the remaining five cities are in the province's linear urban network.

This paper also presents important aspects of the sustainable development situation within the province as follows:

- Mazandaran province exhibits a fragmented urban network, characterized by a sectoral network in the eastern region and a linear network in the western region.
- The province of Mazandaran demonstrates a pronounced inequality in the rate of sustainable urban development across its territories.
- Cities within the linear urban network generally present a high level of development, indicating positive developmental outcomes.
- Conversely, cities within the sectoral urban network tend to exhibit deprivation and can be classified as deprived areas.
- The province's developing and deprived areas (cities) exhibit significant urbanization, as evidenced by a high population concentration within these regions.



Map 7 Analysis of the spatial organization of urban settlements in Mazandaran province

In another research endeavor, Amir Bakhshi and Divasalar (Bakhshi & Divsalar, 2014)investigated and categorized ecological sustainability factors within coastal cities in Mazandaran, focusing on the integrated coastal management approach. The study centered on the city of Babolsar in Mazandaran as the chosen case study, and the outcomes of this study are as follows:

- Traditional urban management approaches, often neglecting environmental concerns, have increased extensive pressures and an amplified adverse ecological impact along coastal regions. Coastal cities encounter difficulties in fulfilling the requirements of outlying areas.

- The lack of integration of ecosystem-compatible activities in the economic planning and urban management of Mazandaran's coastal cities has reduced the agricultural sector's role within the urban and regional economy. This decline is accompanied by the massive land-use change of agricultural areas

for purposes that are not harmonious with the environment, such as residential housing and industrial usage.

- Traditional urban management's disregard for appropriate solid waste disposal and the contamination of surface wastewater has led to widespread pollution across the cities.

To evaluate the environmental sustainability of Mazandaran province, a thorough examination of land-use changes was conducted by Bazi (Bazi, 2014). The study aimed to uncover the multifaceted factors influencing the region, encompassing uncontrolled urban growth and expansion, deficient procedures in converting villages into cities, the subsequent establishment of urban infrastructure and agricultural lands, and the construction of industrial towns near urban and rural industrial areas. The collective impact of these factors has led to environmental unsustainability within the northern provinces of Iran.

Bazi (Bazi, 2014) highlights that the process of urbanization in the northern provinces of Iran has resulted in significant environmental consequences, including:

- Insufficient management and disposal of domestic, industrial, and agricultural wastewater leads to river and wetlands pollution. This pollution adversely affects fish populations and disrupts the natural reproductive areas of aquatic organisms.

- Inadequate waste management practices beyond the urban areas and along roadways result in soil pollution and degradation.

- The proliferation of urban sprawl has led to the conversion of natural landscapes and the loss of vegetation cover through deforestation.

- These findings emphasize the urgent need for improved urban planning and sustainable management strategies to mitigate the negative environmental impacts of urbanization in Iran's northern provinces.

To assess the challenges impeding sustainable development in Mazandaran, it is necessary first to describe the province states' concerning sustainable development pillars, which include environmental, economic, and socio-cultural aspects. The following sections provide a data-driven assessment of the current state of affairs and the challenges the Mazandaran spatial organization faces in pursuing long-term sustainability.

5.3.1 Economic Development

The province of Mazandaran is well-known for its diverse economic activities and abundant natural resources. Regarding the province's economic development, agriculture, fisheries, tourism, the industrial and manufacturing sectors, and transportation are the most important economic infrastructures (Mazandtarh Consulting Engineers, 2010a).

Agriculture: The province of Mazandaran's fertile soil and favorable climate make it suitable for farming activities, allowing Mazandaran to play an important role in Iran's agricultural economy (Azimi, 2013). The many agricultural products produced in this region are rice, tea, citrus fruits, nuts, vegetables, and livestock, with rice cultivation particularly important to the province (Alipour et al., 2013).

Concerning the natural potential and socioeconomic benefits of fisheries and aquaculture development, it has been elevated as one of the priorities of the Islamic Republic of Iran's second to fifth national fisheries programs over the last decade. Aquaculture's widespread availability and development are also important for increasing employment, exportation, and rural development in rural areas. Mazandaran has a unique infrastructure and economic benefits in this field (Salehi et al., 2016).

Commercial fishing opportunities abound along the province's northern coastline, which borders the Caspian Sea. Mazandaran and the southern provinces of Iran are known for their fisheries economy. The Caspian Sea serves as a source for a variety of fish species, including the Kilka fish and Sturgeon fishes, which is particularly for Sturgeon fishes which are renowned for their caviar and play an important role in Iran's fisheries economic sector (Parichi et al., 2023).

Mazandaran Province is a popular tourist destination due to its natural attractions, which include picturesque forests, mountains, and the coastline of the Caspian Sea. The province offers ecotourism, beach tourism, and cultural tourism opportunities (Mosammam et al., 2016; Solymannejad et al., 2022). In Mazandaran, popular tourist destinations include Ramsar, Chalus, and the Hyrcanian forests, and the province hosting yearly for over 15 million tourists from other provinces of the country (Statistical Center of Iran, 2016).

Diverse industries, including food processing, textile manufacturing, pharmaceuticals, and cement production, have seen expansion in the province's industrial and manufacturing sectors. Industrial parks, such as Qaemshahr industrial city, contribute to the economic growth of the province by attracting investments and creating employment opportunities (Mazandtarh Consulting Engineers, 2010a).

Besides, transportation plays a crucial role in the economic system of Mazandaran Province (Mazandtarh Consulting Engineers, 2010a). Its advantageous proximity to Tehran, Iran's capital city, contributes to its transportation activities, facilitated by well-established highways and railways. Furthermore, an international airport in Sari enhances domestic and international travel, serving as a hub for passenger and tourist mobility within Mazandaran and the eastern regions of Iran (Rasoli et al., 2016).

In addition to transportation's significance for passenger mobility, it also plays a vital role in supporting the province's agricultural exports. Mazandaran, known for its agricultural production, experiences a substantial flow of exports to various provinces, with Tehran being a particularly important destination. The transportation sector,

intertwined with agriculture, becomes a key driver of the Mazandaran economic system, facilitating the efficient movement of agricultural products from the province to markets in Tehran and beyond (Sharifi & Sadeghpour, 2006).

Despite the previously mentioned factors, Mazandaran Province faces several spatial challenges that impede its economic development. The following key issues are addressed in the policy and development document for Mazandaran (Mazandtarh Consulting Engineers, 2010a):

- Less developed transportation system: The region faces challenges in efficiently planning, development and operation its transportation system. This implies that inefficiencies exist in developing and optimizing transportation routes, modes, and infrastructure to meet the increasing demands of economic activities.

- Environmental conservation and agricultural benefits are overlooked in planned industrial activities: The value of environmental preservation and the potential benefits of agriculture are frequently overlooked in industrial activity planning and implementation. This oversight may have negative environmental consequences as well as underutilization of the province's agricultural resources for long-term economic development.

- Inadequate infrastructure for industrial, scientific, and multimodal mobility: Mazandaran province lacks adequate infrastructure to support industrial, scientific, and multimodal transportation systems' mobility needs. This shortage may impede the free flow of goods, services, and knowledge, limiting the province's economic growth and innovation capacity.

These obstacles to Mazandaran Province's economic development are significant, and overcoming them would necessitate careful planning, strategic investments, and policy interventions to improve transportation management, promote environmentally conscious industrial practices, and develop robust infrastructure for diverse mobility needs.

5.3.2 Socio-cultural development

Mazandaran's regional development plan prioritizes human resources, societal well-being, and social status, and it also encompasses a range of strategies aimed at safeguarding and enhancing the distinctive cultural identities of its communities. Also, the preservation and promotion of traditional arts, crafts, music, and literature, which form an integral part of the local culture, are key objectives (Mazandtarh Consulting Engineers, 2010b).

Furthermore, the province is renowned for its wealth of historical and archaeological sites, including ancient cities, fortresses, and religious monuments, and these sites not only serve as cultural treasures but also attract tourists interested in exploring the region's deep-rooted history and heritage (Alaei & Mirriahi, 2015; Khalili & Rezaei, 2020).

In recent years, Mazandaran has increasingly emphasized organizing cultural events, festivals, and exhibitions to showcase its cultural diversity. These endeavors foster active community engagement, raise cultural consciousness, and nurture a stronger sense of identity and pride among its inhabitants.

Also, according to Behzadi and Imam Gholizadeh (Behzadi & Imam Gholizadeh, 2018), educational institutions and cultural centers within Mazandaran play a crucial role in advancing cultural development. By offering various courses, workshops, and activities centered on local traditions, languages, and arts, these institutions contribute to transmitting cultural knowledge and preserving Mazandaran's cultural heritage.

Despite persistent endeavors to encourage cultural development in Mazandaran province, specific spatial shortcomings have emerged as impediments to sociocultural development. These deficiencies are underscored not only in the studies as mentioned earlier but also in policy and development plans:

- Inequality in sociocultural development between the province's western and southern regions: Disparities in social and cultural opportunities and resources exist between these areas, causing an imbalance in sociocultural development.

- Non-governmental organization (NGO) activity is unbalanced: The distribution and engagement of NGOs across the province is uneven, resulting in disparities in the promotion and support of cultural initiatives and activities.

- Lack of robust social networks in developed areas: The lack of robust social networks in Mazandaran's more developed regions restricts the exchange of cultural ideas, collaborations, and community engagement, impeding sociocultural development.

- Local and regional governments ignore polycentric spatial typology: Inadequate allocation of resources and support for cultural development in various areas of the province results from a failure to recognize and accommodate the polycentric nature of spatial organization, in which multiple centers of cultural activity coexist.

- For example, housing access and unemployment rates reflect a lack of progress along the province's eastern coast: Mazandaran's eastern coastal region faces challenges in terms of housing availability and employment opportunities, indicating a lag in sociocultural advancement in this region.

It is critical to address these spatial deficiencies to ensure equitable sociocultural development throughout Mazandaran province. Efforts should be directed toward reducing regional disparities, encouraging balanced NGO engagement, fortifying social networks, recognizing and accommodating polycentric spatial patterns, and addressing development gaps in the eastern coastal region. By addressing these challenges, Mazandaran can foster a more inclusive and vibrant sociocultural environment for its residents.

5.3.3 Environmental Protection

Mazandaran Province is well-known for its diverse and environmentally significant environments. Here are some key aspects of Mazandaran's environmental situation:

- Biodiversity: The Hyrcanian forests, a UNESCO World Heritage site and one of the world's oldest and most diverse forests, are found in Mazandaran and these forests are home to a diverse array of plant and animal species, including many that are rare or endemic. Wetlands, coastal areas, and rivers support various ecosystems and contribute to the province's biodiversity (Ghorbani et al., 2023).

- Forest Preservation: Forest preservation is a major environmental issue in Mazandaran. Illegal logging and unsustainable timber harvesting practices have jeopardized forest integrity, resulting in habitat loss and biodiversity decline(Zahed et al., 2022). Stricter regulations, the establishment of protected areas, and public awareness campaigns have all been used to combat these issues.

- Water Resources: Mazandaran benefits from rivers and groundwater resources, critical for agriculture and ecosystem preservation. On the other hand, water scarcity and pollution are issues in some areas due to ineffective water management, agricultural practices, and industrial activities (Taherpourmansour & Salehi, 2021). Sustainable water resource management, including water conservation and pollution control measures, is critical for maintaining a healthy water environment (Abbasi et al., 2013).

Also, Mazandtarh Consulting-Engineers developed the Mazandaran regional development plan in 2010 (Mazandtarh Consulting Engineers, 2010c), which includes several strategic environmental measures. These strategies include protecting strategic areas such as seas, forests, and mountains, implementing comprehensive environmental management approaches such as integrated coastal area management, and establishing comprehensive waste management systems within residential areas.

However, several significant impediments to environmental sustainability and protection exist within Mazandaran province, according to the policy document provided in the vision plan (Mazandtarh Consulting Engineers, 2010c) and Iran's integrated coastal management plan (Pak & Farajzadeh, 2007); among these impediments are:

- High spatial proximity of settlements: concerning the polycentric spatial structure of the province, settlements' proximity exacerbates environmental challenges in Mazandaran province. The concentration of human activities and rapid development in such areas puts additional strain on natural resources and ecosystems, resulting in increased pollution, habitat fragmentation, and conflicts between developmental needs and environmental preservation.

- Environmental destruction activities: Environmental degradation activities are prevalent throughout the province's regions. Illegal and uncontrolled land-use changes and unsustainable agricultural methods are examples of such practices. Such activities cause deforestation, soil erosion, and biodiversity loss, jeopardizing the long-term sustainability of Mazandaran's natural resources.

- Inadequate waste disposal practices and insufficient environmental protection measures: Mazandaran province faces challenges due to insufficient waste disposal practices and environmental protection measures. Improper waste management, both municipal and industrial, can lead to water contamination, air pollution, and negative health effects. Furthermore, the lack of comprehensive environmental protection measures, such as regulatory monitoring and enforcement, impedes effective conservation efforts.

- Significant changes in land use, particularly in agricultural and protected areas: Mazandaran province has seen significant changes in land use, particularly in agricultural and protected areas. Soil degradation, loss of natural habitats, and decreased biodiversity have resulted from expanding human settlements and

urban development activities without proper land management practices. Encroachments on protected areas and inadequate protection measures jeopardize the conservation goals established for these ecologically important areas.

Addressing these challenges will necessitate a multifaceted approach that includes sustainable land-use planning and urban development, improved waste management systems, improved environmental monitoring and enforcement, and promoting sustainable practices in industries, agriculture, and urban development. Collaboration among government officials, local communities, non-governmental organizations, and other stakeholders is critical to overcoming these challenges and ensuring Mazandaran province's long-term environmental sustainability and protection.

Considering the previous discussions and regional upstream documents of the sustainable development plan, the author identifies below essential components, existing challenges, and practical barriers in the pursuit of regional sustainable development in Mazandaran:

In wrapping up this section, it becomes evident that Mazandaran province in Iran faces many challenges on its journey towards realizing sustainable development. These challenges include insufficient spatial coverage of the urban hierarchy in the western and southern regions, resulting in development and resource allocation imbalances. In addition, the province lacks adequate regional services and infrastructure to support sustainable development initiatives, impeding progress in different fields related to the province's development. The following points highlight the most important concerns in this regard.

- The linear structure of mobile networks, as well as their reliance on traditional modes of transportation, contribute to inefficiencies and limited connectivity, while the lack of multimodal transportation facilities results in inefficiencies within the mobility system. Furthermore, unequal access to the mobility system across social groups exacerbates social inequalities within the province.

- Mazandaran's polycentric spatial structure exposes flaws in the social trust network, stifling collaboration toward long-term development goals. The urban network's hierarchical structure and the presence of three distinct homogeneous social network areas create disparities and challenges for fostering cross-regional collaboration.

- Uncontrolled urban sprawl in environmentally sensitive areas and between residential and high-activity zones degrades the environment and disrupts the balance between living and working spaces. The province's numerous partner cities complicate the coordination and alignment of sustainable development efforts even more.

- Other challenges include inequality in sustainable urban development, urbanization and population concentration, environmental challenges due to overlooked considerations, imbalanced population distribution, insufficient transportation system, inadequate infrastructure for industrial and multimodal mobility, sociocultural disparities, and challenges in the eastern coastal region.

Addressing these challenges is crucial for Mazandaran to achieve sustainable development, foster balanced growth, protect the environment, and promote social equity.

5.4 Transportation network characteristics of Mazandaran province

Mazandaran province has a diverse road network that serves as the critical regional infrastructure for transportation. The province's road system comprises various types of roads, each serving a specific purpose in terms of facilitating travel and connectivity (Dehghan farouji & Beitollahi, 2023).

The province has a lower proportion of freeways than the rest of the country, with only 1% of the country's road network falling into this category. Similarly, four-lane

roads account for 4.7% of the road network, providing efficient and higher-capacity travel options. Main roads, which account for 2.2% of the road network, connect the regions (Mazandtarh Consulting Engineers, 2010a; Statistical Center of Iran, 2016).

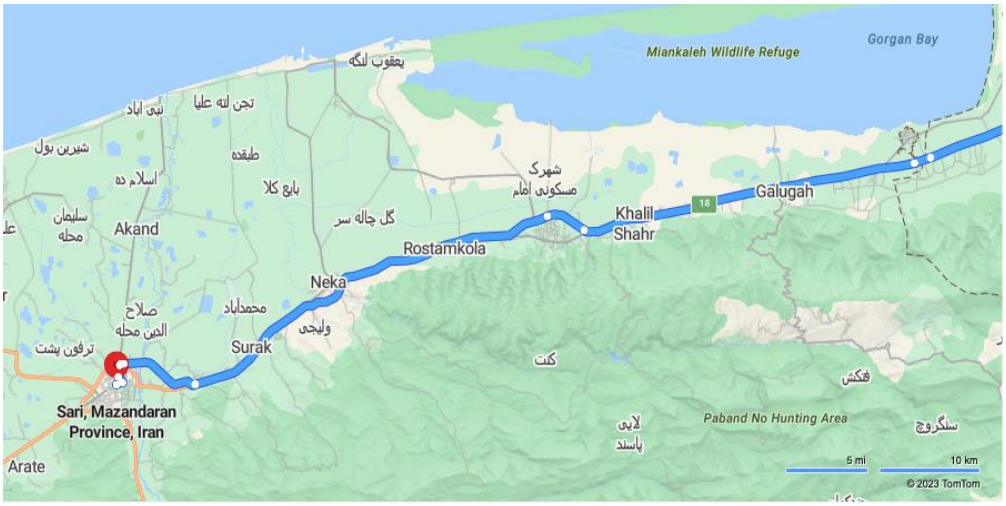
Despite its small share of freeways and main roads, Mazandaran's road infrastructure is in high demand due to its large population, which accounts for approximately 4% of the country's total population, and the high volume of displacements, which accounts for approximately 6% of the national figure. This highlights the importance of continuing investment and development in the road network to meet the transportation needs of the province's residents and visitors (Iran Road Maintenance & Transportation Organization, 2023).

The prevalence of rural roads in Mazandaran is notable, accounting for more than 73% of the province's roadways. Although these rural roads transport fewer passengers and cargo, they are critical for connecting remote areas, agricultural regions, and natural attractions. These roads benefit local communities, make agricultural activities easier, and promote tourism by providing access to Mazandaran's scenic landscapes (Mazandtarh Consulting Engineers, 2013).

The provinces of Golestan, Semnan, Tehran, Alborz, Qazvin, and Gilan border Mazandaran. Several bridges connect Mazandaran with neighboring provinces, allowing for smooth transportation and fostering regional connectivity.

According to the Iran Road and Transportation Organization report (Iran Road Maintenance & Transportation Organization, 2023), the following routes can be named to outline the major connectivity axes within Mazandaran:

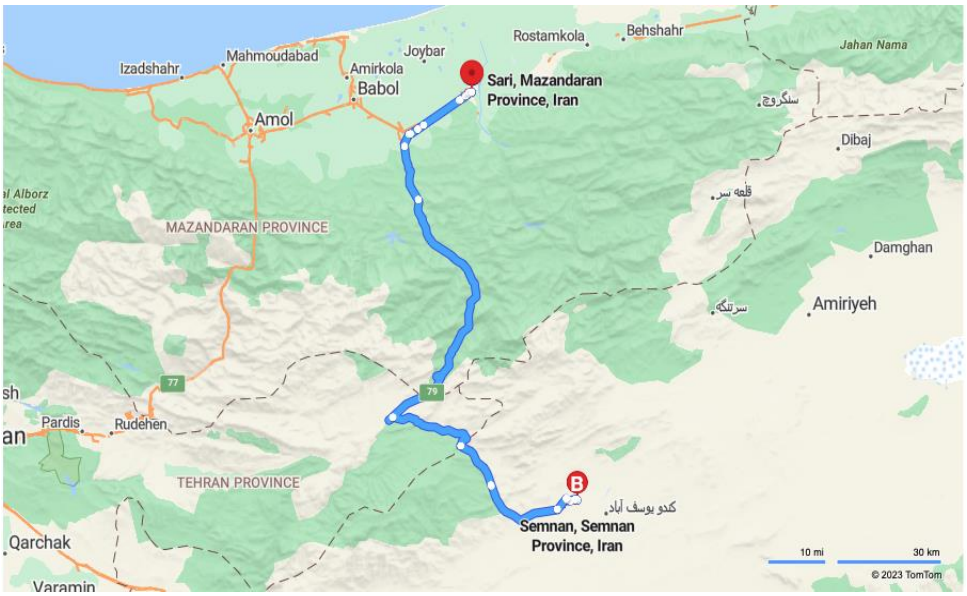
- Gorgan axis: The Gorgan axis runs east-west through the province and provides vital access to the country's eastern region. This route connects the province of Golestan and beyond, facilitating regional trade and travel.



Map 8 Gorgan axis: This axis connects Mazandaran to eastern Iran toward Gorgan Province

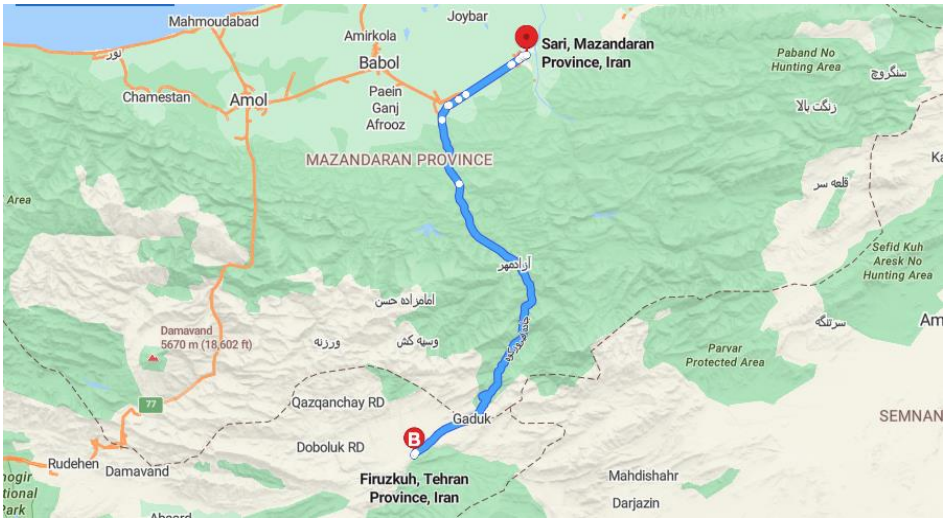
(Resource: Microsoft Bing Maps)

- The axis of Sari-Kiasar-Semnan connects Mazandaran to the neighboring province of Semnan. It provides an important transportation link between the two regions, strengthening economic and social ties.



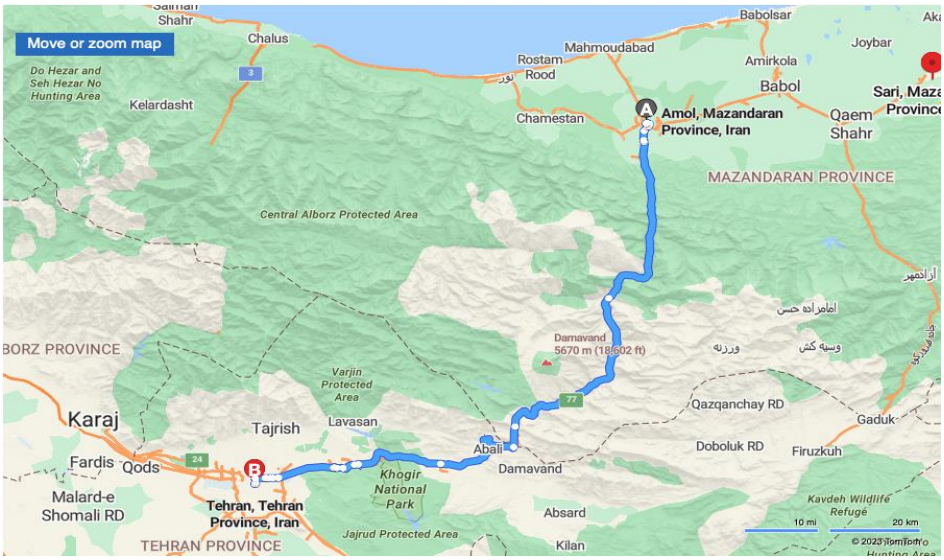
Map 9 Sari-Kiasar-Semnan axis: This axis connects Mazandaran to southern province including Semnan province (Resource: Microsoft Bing Maps)

- Firouzkooh and Haraz axes connect Mazandaran to the capital city, Tehran, from the south. They are important routes for commuters, commercial activities, and transportation between the two regions.



Map 10 Firuzkoh axis: This axis connects central and eastern Mazandaran to Tehran province

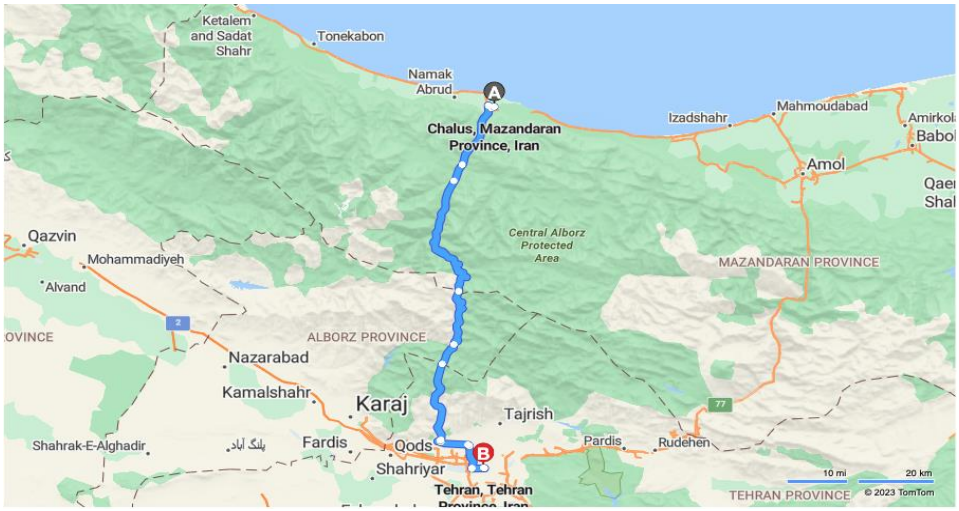
(Resource: Microsoft Bing Maps)



Map 11 Haraz axis: This axis connects central Mazandaran to Tehran province

(Resource: Microsoft Bing Maps)

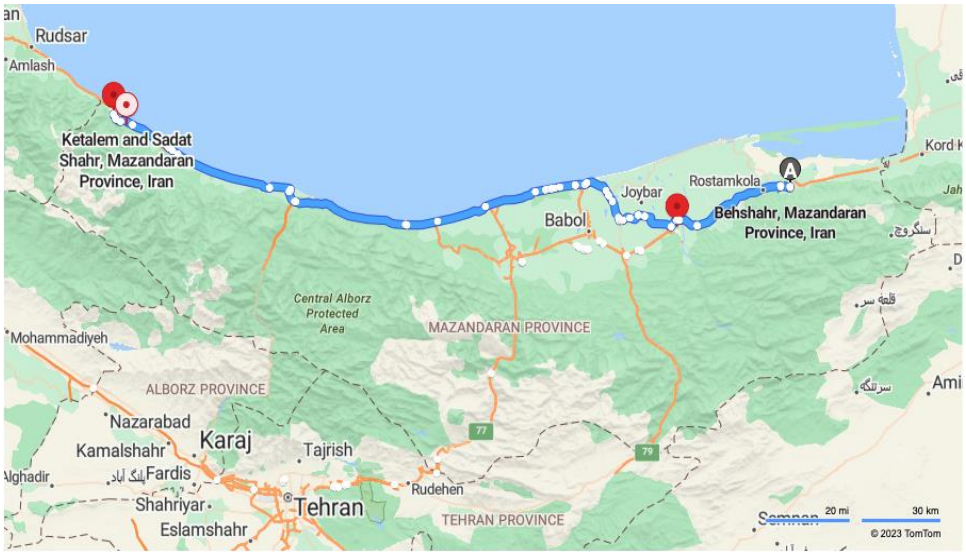
- Kandovan axis: The Kandovan axis connects Mazandaran, Alborz, and other central and southern Iranian regions. It serves as a vital transportation corridor, allowing people, goods, and services to move between these areas.



Map 12 Kandovan axis: This axis connects western Mazandaran to Tehran province.

(Resource: Microsoft Bing Maps)

- The East to West axis runs along the province's coastline, connecting Mazandaran to the neighboring province of Gilan and extending all the way to Azerbaijan. It promotes coastal tourism and trade and cultural exchanges between the regions.



Map 13 The East to West axis: This axis connects Mazandaran cities from East to West

(Resource: Microsoft Bing Maps)

Conclusively, Mazandaran province has a diverse road network that includes freeways, four-lane roads, main roads, and mostly rural roads. Even though the proportion of freeways and main roads is relatively small, the road system plays an important role in meeting the transportation needs of the province's population and supporting economic activity. Mazandaran's axes facilitate regional connectivity and access to neighboring provinces, fostering social, cultural, and economic exchanges.

5.4.1 Rail transportation system in Mazandaran province

The railway infrastructure in Mazandaran province continues to play a role in the region's transportation system despite a lack of significant development in the past two decades. The railway system facilitates the movement of people and goods between Mazandaran and other provinces, including Golestan and Tehran (Mazandtarh Consulting Engineers, 2013).

The main railway line in the region is the Tehran-Gorgan line, which passes through Mazandaran and connects Gorgan city, a city in the neighboring Golestan province, to

Tehran, the capital of Iran. This railway line supports local trade and economic activities by providing efficient transportation for passengers and goods.

The Tehran-Gorgan railway line is situated along Iran's first north-to-west rail route, completed in 1941. This route linked the Rajaie port on the Persian Gulf to the Torkaman port on the Caspian-Sea coast. The route's appeal is enhanced by its passage through the diverse and captivating Mazandaran region, characterized by its mountains, forests, and varying climates. The tourist railway journey from Tehran to Alborz Mountain involves traversing numerous tunnels and bridges, further adding to its allure (Farahbakhsh & Hanachi, 2016).

However, concerning the statistics, Iran's railway network is relatively small in comparison to the country's population and size, indicating the limited availability of railways in Iran compared to other nations. The total length of Iran's railway tracks is 12,998 kilometers, with 363 major stations (Mosayyebi et al., 2022). Mazandaran province has 292 kilometers of railways and 15 of the country's 363 stations within this network (Mazandtarh Consulting Engineers, 2013).

While the length of the country's main railway lines increased by 5% between 1991 and 2004, the length of railways in Mazandaran province remained stagnant, indicating a lack of significant development in the province's rail transportation system. Furthermore, according to statistical yearbooks and data from the Iran National Railway Company (Iran National Railway Company (RAJA), 2018), Mazandaran's share of the country's railway lines fell from 4.4% in 1991 to 2.8% in 2005, highlighting a lack of sufficient attention and investment in the development of the northern region's rail transportation system, despite the obvious need for improvement.

Mazandaran province's rail transportation system comprises interprovincial, national, and international rail lines. However, Mazandaran's intra-provincial rail network is limited to a single train line from Polsefid to Galugah, serving only six counties. The western part of the province has no rail system at all. This train line connects

Mazandaran province to Tehran and the country's larger railway network, running from Polsefid to Gorgan.

The Amirabad port line, which plays a role in transit, is another important rail line in the province. This line connects to the northern rail network and serves as a rail transit corridor, facilitating goods transportation and improving connectivity with other regions and international trade.

In other words, while the rail transportation system in Mazandaran province has some presence and significance, its length and coverage remain relatively limited. The province's share of railway lines has decreased over time, indicating the need for additional attention and investment to develop and expand rail infrastructure to meet the region's transportation needs and support economic growth.

5.4.2 Air transportation system in Mazandaran province

Mazandaran province's air transportation system is critical for quick and efficient transportation of people and low-volume, perishable cargo. The province currently has three airports, one of which is international. Sari Airport is the province's main international airport, with flights to several important domestic destinations. Tehran and Mashhad, two major cities in Iran, are the airport's primary domestic destinations. Furthermore, the airport facilitates international travel by offering flights to countries such as Saudi Arabia and Syria, connecting Mazandaran province to the global network (Shafabakhsh et al., 2014).

An international airport in Mazandaran province improves connectivity and accessibility, promoting tourism, business, and trade. It provides convenient access to the region for domestic and international travelers and is an important economic development gateway. Overall, the Mazandaran province's air transportation system provides a convenient and efficient mode of transportation, particularly for individuals and cargo requiring quick and safe travel. The province's airports contribute to regional

connectivity and play an important role in supporting both domestic and international travel (Mazandtarh Consulting Engineers, 2013).

5.4.3 Water Transportation System in Mazandaran

Mazandaran province's water transportation system, located along the Caspian Sea, is important to the region's overall transportation infrastructure. Water transportation provides distinct benefits for moving goods and people, particularly in coastal areas.

Mazandaran province has several ports and harbors that aid in water transportation. Noshahr, Amirabad, and Fereydunkenar are the province's major ports. These ports serve as important maritime trade gateways, connecting Mazandaran to other regions of Iran and international destinations(Mazandtarh Consulting Engineers, 2013).

- Noshahr Port is a significant commercial port that handles various cargo types, such as containers, bulk commodities, and general goods. It gives access to the Caspian Sea, allowing trade with neighboring countries and beyond.

- Another important port in Mazandaran province is Amirabad Port, which is located near the city of Behshahr. It is an important transportation hub for goods, particularly for industries such as agriculture, fisheries, and construction materials, as well as a link between Iran and Russia. This port also has a good rail connection and is linked to Iran's national rail system, which facilitates trade flows within Iran and to northern neighboring countries.

- Fereydunkenar Port, located in Fereydunkenar, is primarily used for fishing and transporting fishery products. It benefits the local fishing industry, a significant economic sector.

The water transportation system in Mazandaran province is critical for facilitating trade and supporting economic activities. However, it also serves as the international transport system for goods and commodities between Iran and other countries. It offers an alternative mode of transportation, particularly for bulk cargo and non-time-

sensitive goods. The province's ports serve as vital gateways for both domestic and international maritime trade, contributing to the region's economic growth and development.

5.4.4 Transportation administration

Transportation management and planning are being implemented at various levels in Mazandaran. Municipalities are responsible for organizing and managing transportation and mobility within the boundaries of cities, which are mostly just built-up areas, and there are no official mobility public services for the cities suburbs. Private passenger automobiles that provide transportation services are the most common mode of transportation in cities, followed by taxis. Bus lines are also available in some of the province's larger cities. However, Mazandaran's rail transportation system currently plays no role in the mobility system within the cities, and the province lacks infrastructure in this regard.

Regarding regional transportation, the central government oversees organizations that are in charge of developing provincial road networks that connect cities within the province and enable mobility beyond its borders and are mostly planned for road transportation.

Certain cities have central hubs located outside of urban areas that serve people via private passenger automobiles and buses to facilitate regional mobility within cities. While train lines exist in some areas of the province, they primarily serve nationally to connect major cities such as Tehran to other parts of the country, including Mazandaran. This rail network primarily aims to transport goods and commodities, with a secondary focus on passenger transportation. On a regional scale, however, Mazandaran lacks a centralized organization for planning and managing the public transportation network and considering multimodal transportation.

Taking into account the discussions above, the transportation pattern in Mazandaran province, at different levels within and beyond the province, can be summarized as follows:

- Within the province, road transportation is the primary mode of transportation, with rail transit playing a minor role. The volume of marine communications between the province's ports is relatively low, and air transportation within the province is limited and mainly serves travel outside of Mazandaran.

- On a regional and national scale, road transportation remains significant. While there has been a shift from road to rail and air transportation for certain journeys, marine transportation remains relatively low.

- Due to a lack of an international land border with neighboring countries, Mazandaran province relies on indirect international connections through road and rail lines. Unfortunately, the province lacks a comprehensive, integrated planning and operational framework for managing mobility at different scales.

5.5 Sprawl in Mazandaran polycentric city-region

Concerns have been raised recently about urban sprawl in Mazandaran, particularly in some of its larger cities such as Sari, Babol, and Amol (Salarian & Dadashpoor, 2018). As the rate of population growth and urbanization has accelerated, so has the demand for housing, infrastructure, and services, and this has resulted in the expansion of urban areas, which is frequently characterized by the outward growth of residential and commercial developments without adequate planning and infrastructure provision (Dadashpoor & Salarian, 2020). Urban sprawl's strain on existing infrastructure and resources is one of the most significant challenges. Urban areas need to develop roads, utilities, and public services (Hogan & Ojima, 2008). Such expansion can sometimes result in insufficient infrastructure, traffic congestion, and environmental degradation (Sudhira et al., 2004).

It is important to note that the extent of sprawl in Mazandaran varies across the province (Hosseini et al., 2013). Unplanned development may be more prevalent in some areas, while others may have stricter regulations to manage growth. The local government's commitment to sustainable development and effective urban planning will be critical in mitigating the negative effects of Sprawl and ensuring a balanced and livable environment for Mazandaran residents (Salarian & Dadashpoor, 2018).

Ghadami et al. (Ghadami et al., 2020) believe that given Iran's fast urbanization, expanding number of cities, and growing population, cities grew and expanded quickly, so much so that physical development surpassed population growth. Mazandaran's Sprawl is a result of unregulated growth and horizontal expansion. This study investigates the stages and patterns of physical growth in Mazandaran by examining Kiyakola throughout the previous decades. As the political capital of Simorgh, the city has grown rapidly in recent years. The study uses descriptive and analytical methodologies to determine the direction and shape of physical development using models such as spatial population density analysis, Moran's spatial autocorrelation methods, and GIS hot spots. The city's physical expansion between 1976 and 2006

was fragmented and non-condensed, providing the framework for quick growth without planning. A geographic study shows cluster distribution and spatial autocorrelation in population, housing, and building density. The west and center of the city are the hottest, while the east and southeast are the coolest.

Dadashpoor and Salarian (Dadashpoor & Salarian, 2015b) investigated the impact of population and land development on sprawl in another study. The study concentrated on Mazandaran's eastern coastal cities, including Sari, Babol, and Qaemshahr. This comprehensive study considers the population, services, labor, and management concentrations in Mazandaran from 1985 to 2010. This urban region is significant in terms of population density, service provision, job opportunities, and administrative centers. Despite increased land development and expansion in the study area, population growth has remained moderate. Given the significance of studying urban areas and their growth patterns, this research aims to investigate and assess the impact of population characteristics and land development on the distribution of urban land.

The urban population increased significantly after the Islamic revolution, which prompted the growth of cities and more urban land development (Buhaug & Urdal, 2013). However, as the population growth rate slowed, there was a noticeable shift in habitation patterns in urban areas such as Mazandaran. This shift resulted in a significant expansion of services and infrastructure that exceeded people's actual needs. As a result, urban land development has slowed in favor of peripheral growth with lower population density, leading to housing sprawl (Dadashpoor & Salarian, 2015b).

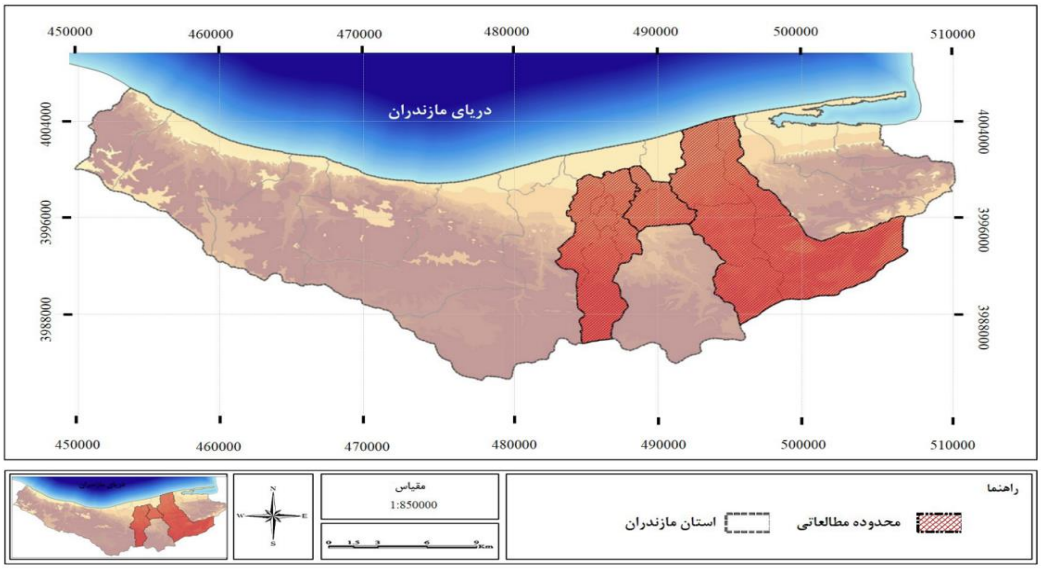
According to Dadashpoor and Salarian (Dadashpoor & Salarian, 2015b) discussion, land development in Mazandaran increased by more than 100% between 1986 and 1996. However, population growth was minimal during this period. Sprawl increased by 1.35% between 1996 and 2006, roughly in line with population growth. However, after that, Sprawl began to decline. From 2006 to 2011, this trend continued, though the rate of Sprawl slowed. Also, from 1986 to 2011, the density equilibrium factor,

which measures the balance between population density and land development, indicated a variable process. The score between 1986 and 2006 was 10.9, indicating the greatest level of Sprawl. This could be attributed to increased land development and property sales in 1986. From 1996 to 2011, the score fell to 4, indicating a decrease in Sprawl. Overall, Sprawl stopped from 1986 to 2006, while from 1986 to 2011, Sprawl experienced uneven growth.

In a different study by Salarian and Dadashpoor (Salarian & Dadashpoor, 2018), micro-scale Sprawl tendencies in the central city-region of Mazandaran were examined using quantitative research techniques and the Urban Growth Form (UGF) model. The UGF model is a tool that can identify and characterize various types of Sprawl patterns in great detail. Salarian and Dadashpoor (Salarian & Dadashpoor, 2018) identified three distinct Sprawl patterns in the studied region using this model: linear, infill, and leap-frog. Each pattern represents a unique type of urban growth and development. The linear pattern refers to extending urban areas along major roads or transportation corridors. The infill pattern represents the filling of voids within existing urban areas. Finally, the leap-frog pattern denotes scattered urban development, frequently skipping over spaces between existing developments.

Salarian and Dadashpoor's (Salarian & Dadashpoor, 2018) study of the investigated area reveals macro-level Urban Sprawl. The spatial plan in 1986 was focused on three urban hubs, and Sprawl was observed on the outskirts of these hubs, particularly in Sari. Babol's population increased in 1996 due to urbanization in certain rural areas and the expansion of adjacent territories. Babol and Qaemshahr, on the other hand, experienced relatively little Sprawl. On a micro-scale, the spatial Sprawl trends appeared linear from 1986 to 1996 and 1996 to 2006, coinciding with the expansion of metropolitan areas and peri-urban lands. The expansive development followed an infill pattern between 1986 and 1996, resulting in a hybrid linear-infill structure. From 2006 to 2016, the spatial expansion pattern was infill. A separate analysis of urban and rural communities yielded different results. Urban Sprawl was linear and dispersed, whereas rural Sprawl was linear and infill. Mazandaran's core city region has grown as

a result of rural development. Whether planned or unplanned, residential development has resulted in cities and their outer borders being expanded into Mazandaran's agricultural lands. This demonstrates the impact of both urban and rural factors on regional Sprawl.



Map 14 Boundaries of studies area by Salarian and Dadashpoor in Mazandaran

(Salarian & Dadashpoor, 2018)

Kamanroodi et al. (Kamanroodi et al., 2020) investigated Babol's expansion, spatial attributes, and spatial shape from 1957 to 2017. Babol is a major city in Iran's Mazandaran Province, located in the country's northeastern part. The city's population, economic function, and geographical location contribute to its prominence within the province. Their study used the Holdren model to calculate Babol's Sprawl. According to the study, Babol grew between 1957 and 2017. According to the Holdren model, population growth accounts for 74% of the city's horizontal expansion during this period, while Sprawl accounts for 26%. Between 1957 and 2017, 16 towns in the surrounding area were incorporated into Babol, expanding the city.

Kamanroodi et al. (Kamanroodi et al., 2020) emphasize the linear relationship between the northern and southern axes and Babol dispersion. Outlying villages have grown physically, reshaping the structure and functions of Babol. The construction of public housing complexes, the migration of impoverished individuals to the outskirts, and the absence of natural barriers have all contributed to the city's growth. The interurban axis, particularly along the Babol-Babolsar, Babol-Babolkenar, and Babol-Bandpe routes, has played an important role in Babol's northward expansion. The study examines how west-to-east transit roads in Mazandaran influenced westward and eastward growth. The majority of Babol's settlements are arranged along these connecting axes. According to the research findings, Babol's Sprawl pattern most likely followed a linear trajectory along multiple axes during the study period.

5.5.1 Sprawl Consequences on the sustainable regional development of Mazandaran

Urban Sprawl has brought about a significant transformation in the spatial arrangement of Mazandaran Province, leading to evident and undesirable spatial consequences that impact its environment, society, culture, and economy. As a result, addressing the issue of Urban Sprawl has become an urgent priority within the governance framework and the pursuit of lasting and sustainable development in the province. Given the prevailing challenge posed by Urban Sprawl, effective planning and management strategies necessitate a thorough comprehension of the factors driving this phenomenon. This understanding, in turn, facilitates the development of appropriate and impactful measures to counteract its effects (Salarian et al., 2023).

In a study by Salarian et al. (Salarian et al., 2023), the researchers aimed to enhance their understanding of the challenges posed by Sprawl in the central city region of Mazandaran Province. They also proposed effective strategies to tackle these challenges. The study specifically focused on the cities of Sari, Qaemshahr, Babol, and Amol, considering that although these cities occupy only 30% of the province's land area, they accommodate 53% of Mazandaran's population.

Salarian et al. (Salarian et al. 2023) research covers two major viewpoints—spatial and non-spatial—as the study's framework. Spatial changes in land use, housing, land demand, expanding transportation and infrastructure, and ineffective land development all impact Sprawl. Socioeconomic, environmental, and management issues affect Sprawl non-spatially. Sprawl is complicated because its causes and effects change. Insufficient Sprawl control and supervision leads to development inefficiency, extensive land use change, degradation of natural lands, rapid growth, rising land and housing prices, the proliferation of temporary and second housing patterns, unplanned residential center formation, spatial imbalances, the transformation of peri-urban and rural landscapes, and urban-rural hybridization. These issues make the physical and spatial subsystems of the planning environment and spatial development processes more difficult.

Within the area examined by Salarian et al. (Salarian et al., 2023), their study unveiled several predominant drivers of Urban Sprawl in Mazandaran. These included household income, land and housing marketing dynamics. Moreover, the study delved into the outcome of Urban Sprawl, revealing its adverse effects on the economy, its impact on hindering effective regional management and governance, the negative consequences it posed for indigenous communities and culture of the region, and also its potential to reshape the physical landscape of the region.

The research recommends applying regulatory reforms, economic policies, and market modifications to address these problems. It suggests actions to mitigate environmental damage, update regional land use plans, prevent land speculation, limit building permits, prioritize low-value land for development, and foster sustainable neighborhoods.

In another effort to deal with the matter of Sprawl in Mazandaran, Salarian and Dadashpoor (Salarian & Dadashpoor, 2018), performed a quantitative analysis to investigate the spatial patterns of Sprawl in the foremost city-region of Mazandaran

province, focusing on Sari, Babol, and Qaemshahr cities. They collected demographic data from the Statistical Yearbooks of Mazandaran Province from 1986 to 2016 and obtained physical-spatial data using remote sensing imagery, maps, and urban growth models. They utilized the Kriging Estimator and the urban growth form (UGF) model to analyze Sprawl's macro-scale and micro-scale spatial patterns, respectively.

The results of Salarian and Dadashpoor (Salarian & Dadashpoor, 2018) show an increase in Urban Sprawl on the macro scale during the study period. Initially 1986, Sprawl was concentrated around three main urban centers, notably Sari. However, by 1996, there was a shift in concentration toward Babol, accompanied by limited Sprawl in some areas of Babol and Qaemshahr. This trend continued until 2006 when the Sprawl phenomenon intensified across urban, peri-urban, and rural lands. In terms of micro-scale spatial patterns, from 1986 to 1996, there was a linear pattern of Sprawl, implying development along the periphery of urban territories. However, from 1996 to 2006 and 2006 to 2016, the way shifted towards infill development.

The study by Salarian and Dadashpoor (Salarian & Dadashpoor, 2018) result indicates too urban lands exhibited a dispersed and linear pattern of sprawl, while rural settlements displayed a linear and infill pattern. The expansion of cities and their peripheral areas into agricultural lands has been driven by residential construction, planned or unplanned. This phenomenon has had significant implications for the region's economic capacity, which relies heavily on agricultural development. To mitigate further destruction and uncontrolled growth, a specific plan should be implemented to safeguard the lands and regulate construction activities, considering the current state of the land and housing market.

In the subsequent phase of the study, Salarian and Dadashpoor (Salarian & Dadashpoor, 2018) modeled and simulated land development and changes until 2031 (1410 in the Iranian calendar). The aim was to predict the anticipated land-use alterations and how the land would be utilized during that period.

The research findings indicate that in 2031, there is projected to be a decrease in agricultural land use and garden land use, with a negative rate of 1.43%. Conversely, the constructed areas and regions are anticipated to experience a positive growth rate of 4.85%. The concentration of built areas will be predominantly observed in the northern parts of the region, while a similar increasing trend might be kept in the western and eastern areas.

In studying the significance of land use change in the rural areas of central Mazandaran, Hashempor et al. (Hashempor et al., 2019) focused on the Sari region's rural areas. The conversion of agricultural land has become a significant issue in the Iranian agricultural sector, particularly in Mazandaran, as it results in the loss of fertile farmland from cultivation.

According to Hashempor et al. (Hashempor et al., 2019), the main goal of this analysis was to assess the effects of changing agricultural land use and Sprawl in rural areas. The study's statistical population comprised the rural regions of Sari, specifically villages with a population exceeding 500 individuals. The applied method was stratified random sampling to select a sample of 25 different locations representing rural villages. The Cochran Formula was employed to determine a sample size of 381 families, who were subsequently administered a questionnaire.

In the study by Hashempor et al. (Hashempor et al., 2019), descriptive and inferential data showed that agricultural land decreased by 25.4% between 2007 and 2018. As a result of land use change and subsequent spread in rural regions, the natural landscape of the villages also faced significant issues, such as sprawl, an increase in land transactions, unlawful development, weak local management, and inadequate enforcement of regulations. These difficulties increase the likelihood of natural disasters like floods, earthquakes, and landslides, threatening the long-term viability of the environment.

In a recent study conducted by Nikpour and Yarahmadi (Nikpour & Yarahmadi, 2022), the phenomenon of dispersed urban development and its extent of sprawl in Sari city,

the capital and largest city of Mazandaran province, was investigated. The findings of this study hold significant implications not only for Sari city but also for other major cities in the region, including Babol, Amol, and Qaesmshahr, which constitute a significant portion of the urbanized area in the region. The study provides valuable insights into urban development challenges and offers strategies for effectively managing urban sprawl in large cities.

Drawing from the study's outcomes, Nikpour and Yarahmadi (Nikpour & Yarahmadi, 2022) identified pivotal indicators of urban sprawl within Sari city, categorizing them into six distinct groups: density, accessibility, net density, irregularity of constructed areas, activity space, and construction components. Upon analyzing dispersed sections within the city, their investigation unveiled that a land area of 176.60 hectares and a resident population of 18,124 were situated in regions with a lower level of sprawl. In contrast, areas with a high sprawl encompassed a land area of 598.31 hectares, accommodating 74,540 residents. The implications of these findings resonate significantly for devising urban development and management strategies, especially within larger cities like Sari city, as well as in neighboring locales such as Babol, Amol, and Qaemshahr.

The Nikpour and Yarahmadi (Nikpour & Yarahmadi, 2022) study extensively discussed the impact of density and accessibility on dispersed land. They found that areas with high levels of land dispersion often face challenges such as poverty, unauthorized land use changes, inadequate infrastructure, and limited access to public services. These issues have contributed to the formation of inefficient urban structures and hindered the population's well-being. Addressing these challenges requires a comprehensive and collaborative approach involving various stakeholders.

The study by Nikpour and Yarahmadi (Nikpour & Yarahmadi, 2022) identified 16 research indicators categorized into six general factors: density, accessibility, gross population density, activity space, construction components, and irregularity. These factors collectively account for 89% of the variance in the urban sprawl phenomenon.

Among them, density and accessibility emerged as highly influential factors. District 2 of Sari city exhibited the largest dispersal zone, covering an area of 535.545 hectares and accommodating 28,624 people. Districts 4 and 3 also exhibited significant levels of dispersion. Overall, Sari has 31,598 hectares of land and 74,540 residents residing in areas with extremely high dispersal, while 176.60 hectares of land and 18,124 residents are in areas with very low dispersal. Out of the 20 districts, 15 have high and extremely high levels of dispersion, as indicated by the final map.

What can be considered by Nikpour and Yarahmadi (Nikpour & Yarahmadi, 2022) The urban sprawl in Sari city exhibits three distinct spatial patterns, as revealed by the study. The first pattern is characterized by continuous low-density development and is observed in areas 3 and 4 of District 2 and in Imamzadeh Abbas and Zoghalchal. These areas were recently incorporated into the city and were previously rural countryside. The second pattern, found in District 1 of District 4 in the Dokhaniat neighborhood near the well-known Rahband district, is characterized by a distinct and inefficient urban fabric. Finally, the third pattern is observed in the city's central district and District 4, both exhibiting a similar trend of internal development. Each of these patterns has unique characteristics and requires different approaches for effective integration.

Lahmiyan (Lahmiyan, 2017) examined the urban development process in Mazandaran, focusing on Sari, using a descriptive-analytical approach from 1335 to 1395. The researcher stressed that understanding the growth and physical development pattern regarding the spatial organization of human activities is crucial for sustainable urban development. This emphasizes the need to thoroughly assess urban development's environmental and social impacts.

In this effort by Lahmiyan (Lahmiyan, 2017), two primary categories were identified: horizontal expansion or Urban Sprawl and the compact city model. Assessing this framework is essential for guiding sustainable urban development. The study's results indicated a decrease in the city's growth and geographical expansion, accompanied by

an increase in density. The rapid urbanization and unregulated migration from rural to urban areas have contributed to an irregular and dispersed pattern of horizontal growth, which is considered undesirable. This unsustainable urban growth in Mazandaran has led to numerous negative consequences in the economic, social, and environmental sectors. These consequences include the loss of agricultural land surrounding the city, degradation and contamination of soil and water resources, air pollution, increased costs of municipal services, heightened consumption of fossil fuels, social inequity, and inadequate resource management.

In light of these findings by Lahmiyan (Lahmiyan, 2017), shifting the trajectory of urban development towards sustainability is imperative. This necessitates modifying and making the city more compact to address the challenges of unsustainable urban growth in Mazandaran.

The study done by Kamanroodi Kojouri and Gholinia (Kamanroodi Kojouri & Gholinia, 2019) focuses on the spatial structure of rural areas surrounding cities in Mazandaran, specifically investigating the expansion of Babol, the second most significant urban center in the region (after Sari), from 1957 to 2017. The study aims to examine the impact of Babol's expansion on the structural and functional changes in nearby villages, with a particular emphasis on Siakolamahaleh.

To assess Babol's Sprawl, Kamanroodi Kojouri and Gholinia (Kamanroodi Kojouri & Gholinia, 2019) employed the Holdren model. According to the model's calculations, between 1957 and 2017, 74% of the city's horizontal growth can be attributed to population growth, while 26% can be attributed to sprawl. This trend has resulted in the integrating of city villages, fundamentally transforming the community on the outskirts of Babol city. The changing and strengthening functional connections between Babol and Siakolamahaleh have shifted the village's structure, economy, and physical functions, transitioning from primarily agricultural activities to services and industries. This process appears to be leading to the incorporation of the village into the urban fabric of Babol. Spatial phenomena such as sprawl are prevalent in large

cities in Mazandaran and contribute to forming new urban settlements that expand near existing villages.

The study conducted by Hosseini et al. (Hosseini et al., 2013) focuses on the western bank of Mazandaran province, specifically examining the areas of Noor, Royan, Babolsar, and Fereydunkenar to assess the debordering effects caused by urban sprawl. The researchers argue that sprawl, characterized by uncontrolled and inappropriate expansion of urban space, is a consequence of the elimination of borders between the cities of Royan and Noor and the influx of rural-to-urban migration. They further suggest that urbanization and the debordering process between cities and villages in western Mazandaran have significantly impacted the rural landscape. The presence of individuals seeking employment opportunities in urban areas, particularly in industrial sectors, as well as suburbanization and uneven expansion of villages around cities, have contributed to these changes. The gradual physical expansion of the metropolis and encroachment upon neighboring settlements have resulted in various physical, economic, and environmental losses.

Hosseini et al. (Hosseini et al., 2013) discuss that, due to its proximity to the city, the economic structure of the village has transformed, shifting from being primarily centered on agricultural production to becoming an enclave situated adjacent to the urban center. Consequently, the village becomes subordinated to the city, with its economic activities being largely influenced by urban development. As a result of the city's physical expansion, the village's agricultural fields have been converted into residential lands accommodating service establishments and workshops. In addition to the gradual growth of a relatively affluent population in the village, which contributes to the increasing land market, the community's social fabric is also undergoing changes, functioning more fluidly. Unregulated and uncontrolled development, coupled with growing housing demands, destabilizes the village's physical structure.

Considering the insights derived from the studies mentioned above and the ongoing debates and discussions revolving around Sprawl and unregulated urban expansion in

Mazandaran, it becomes apparent that these phenomena have cast substantial adverse effects on the region's strides toward sustainable development. These unfavorable consequences manifest across various dimensions, encompassing the economic, social, and environmental spheres. In the context of Mazandaran, several noteworthy consequences linked to Sprawl can be outlined as follows:

Social:

- Sprawl reduces social interaction in rural areas as communities become more dispersed.

- Cultural interference caused by the influence of urban culture on neighboring communities can lead to the erosion of traditional cultural practices and values.

Economic:

- Sprawl led to rising land prices in northern cities and the emergence of a black market for land. This can result in economic inequalities and hinder access to affordable housing.

- The structure of the rural economy tends to deteriorate as land is converted from productive agricultural or horticultural use to residential or commercial purposes. This shift can disrupt the economic vitality of rural areas.

Environmental:

The environmental impacts of sprawl include the following:

- Extinction of plant species due to habitat loss and fragmentation.

- Agricultural and horticultural land is also lost as it is converted to urban development.

- This land use shift further exacerbates the loss of productive agricultural areas. Improper municipal waste management and expansion associated with sprawl contribute to increasing environmental degradation and pollution, including air pollution.

- Sprawl also increases fuel and energy consumption, primarily due to longer transportation distances between cities and the inefficient use of resources.

- Sprawl alters the spatial structure of urban areas, resulting in less compact and inefficient urban forms.

These consequences also highlight the need for comprehensive planning and sustainable development strategies to manage and mitigate the negative impacts of sprawl.

5.6 Impact of the mobility system on the sustainable development of Mazandaran

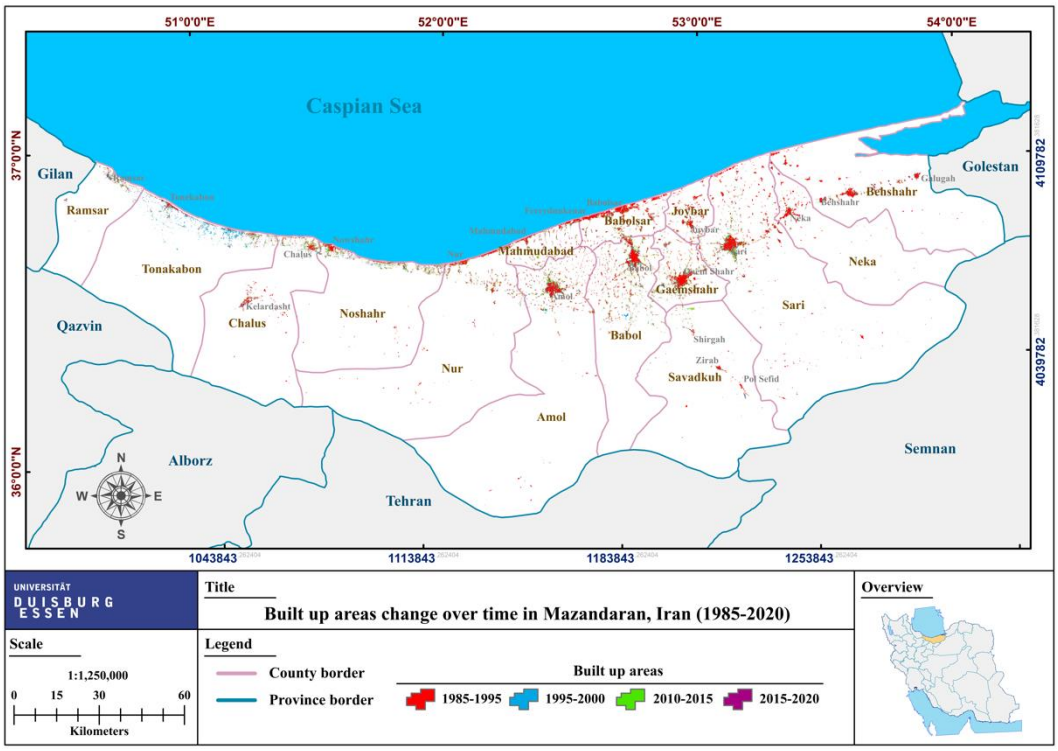
Having precise data for studying and assessing the mutual connection between the mobility system in the Mazandaran polycentric city-region and the province's sustainable development situation was crucial. The subsequent chapter delves into assessing the built-up area in the province of Mazandaran, serving as an environmental indicator. This evaluation encompasses the period from 1995 to 2020.

The length and area of Mazandaran's primary and secondary mobility networks are also examined as indications for addressing the issue. Additional indicators pertinent to sustainable development, encompassing economic and social aspects, have been addressed by referencing data from the provincial statistical yearbook.

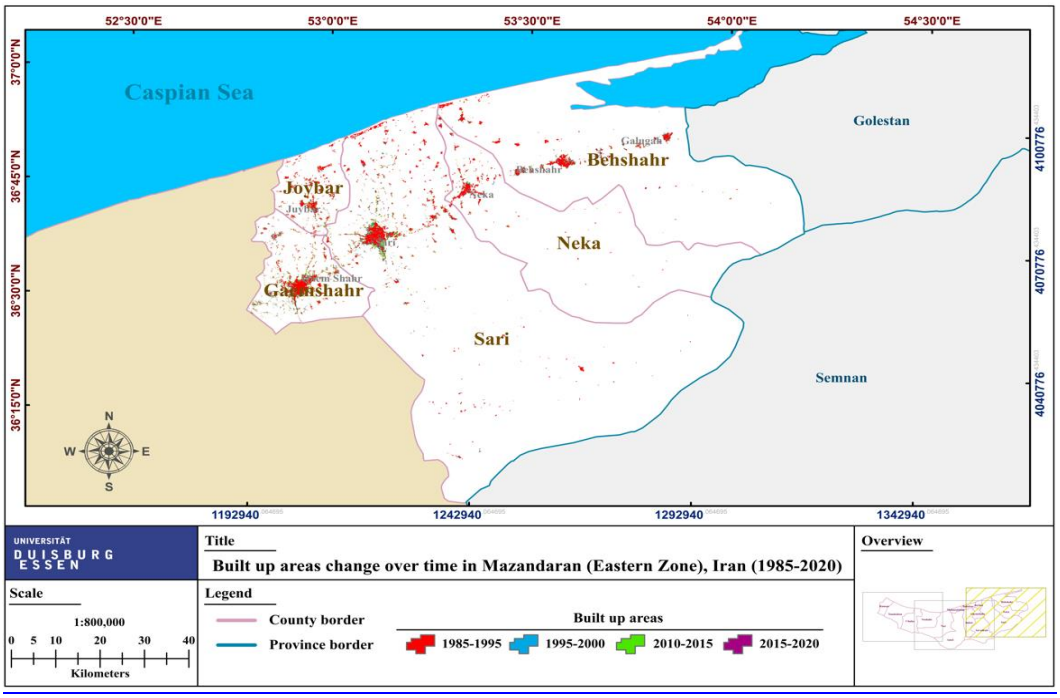
5.6.1 Current situation of sprawl in Mazandaran

In light of the literature review in preceding chapters, sprawl analysis is a pivotal focus within the context. The necessity of generating current statistical data on sprawl in Mazandaran arises from the absence of dependable and consistent regional or local data accessible through public databases or official sources.

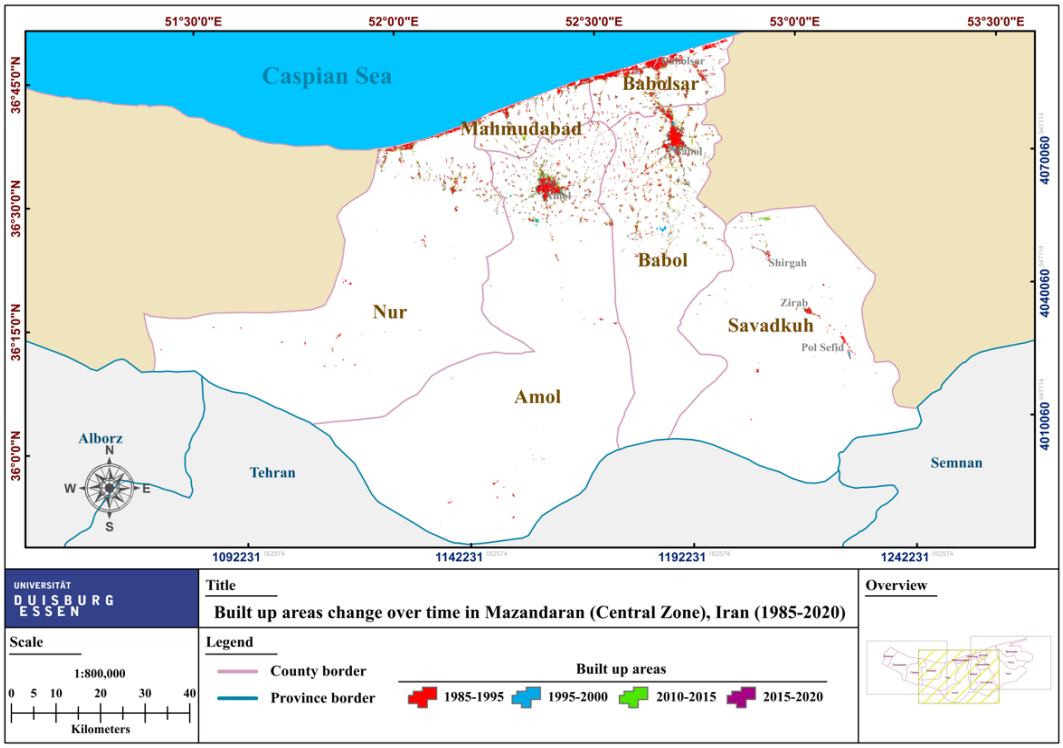
As detailed in the methodology chapter of the study, the evaluation of sprawl conditions in Mazandaran is approached through the lens of urban development and built-up areas. The Mazandaran region has been divided into three distinct sections: Eastern, Middle, and Western counties to ensure a comprehensive understanding of the expansive growth pattern.



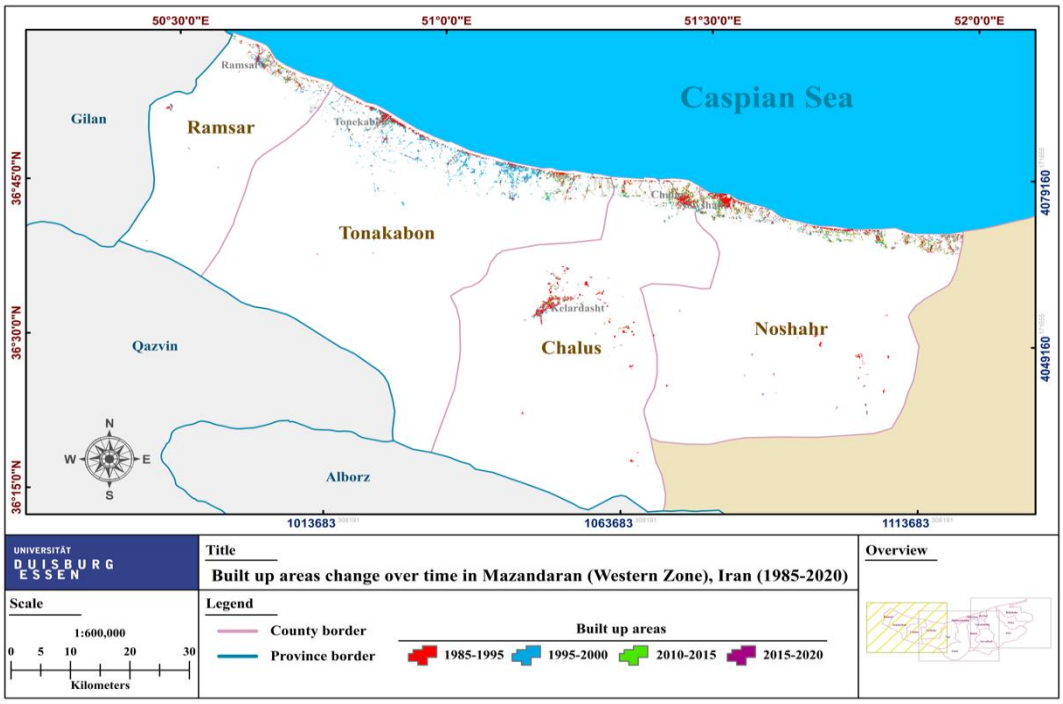
Map 15 Built-Up areas change over time in Mazandaran between 1985-2020



Map 16 Built-Up areas change over time in Mazandaran between 1985-2020- Eastern Zone



Map 17 Built-Up areas change over time in Mazandaran between 1985-2020-Central Zone



Map 18 Built-Up areas change in Mazandaran between 1985-2020-Western Zone.

In addition to the visual representations offered by previous maps, Table 2 provides a comprehensive depiction of the statistical findings derived from accurate remote sensing analyses conducted between 2000 and 2020. It is noteworthy to highlight that the acquisition of precise statistical data for the period spanning from 1985 to 2000 encountered technical constraints, primarily stemming from the limitations of available satellite imagery in terms of quality during the study period. The resulting dataset, encompassing data points gathered at 5-year intervals from 2000 to 2020 and quantifying Sprawl statistics in square kilometers (km2), offers valuable insights into the sprawl phenomenon in the Mazandaran polycentric city-region.

In this comprehensive analysis, advanced remote sensing technology is harnessed to precisely evaluate and quantify the spatial expansion of urban sprawl in Mazandaran. By leveraging cutting-edge technology, the researcher adeptly addresses challenges stemming from limited satellite imagery in earlier years. This approach facilitates the presentation of a comprehensive and reliable portrayal of sprawl dynamics within the specified timeframe.

The outcomes of this analysis yield pivotal insights into the growing urban sprawl and its repercussions on local socioeconomic conditions, environmental sustainability, and land use practices. Through meticulous data analysis, stakeholders can attain a profound grasp of sprawl patterns and trends. This understanding is the foundation for devising effective strategies and policies to tackle challenges and promote sustainable development in Mazandaran.

Table 4 Mazandaran counties sprawl in Km^2 for the duration 2000-2020 in 5-year interval

Counties	Sprawl in Km^2 for the 5-Year interval			
	2000-2005	**2005-2010**	**2010-2015**	**2015-2020**
Neka	18,39	17,9	18,22	18,13
Noshahr	23,75	29,15	32,99	37,2
Juybar	17,5	20,73	21,99	21,57
Ramsar	6,943	7,441	9,185	10,24
Tonakabon	20,15	20,26	25,86	29,42
Chalus	19,91	22,9	24,11	25,7
Nur	21,34	24,57	28,08	34,59
Mahmudabad	19,19	20,61	23,88	28,34
Amol	45,69	49,1	54,48	60,52
Babolsar	43,65	47,31	51,71	54,27
Savadkuh	8,477	9,505	10,34	10,96
Babol	66,33	73,57	78,37	81,43

Behshahr	31,95	32,47	33,21	33,56
Sari	70,55	77,08	80,87	83,28
Gaemshahr	**45,23**	**50,6**	**54,09**	**55,76**

In addition to the provided information, Figure 25 visually presents the sprawl pattern observed in Mazandaran from 2000 to 2020. This graphical depiction succinctly captures the dynamic evolution of sprawl in the region over a twenty-year period.

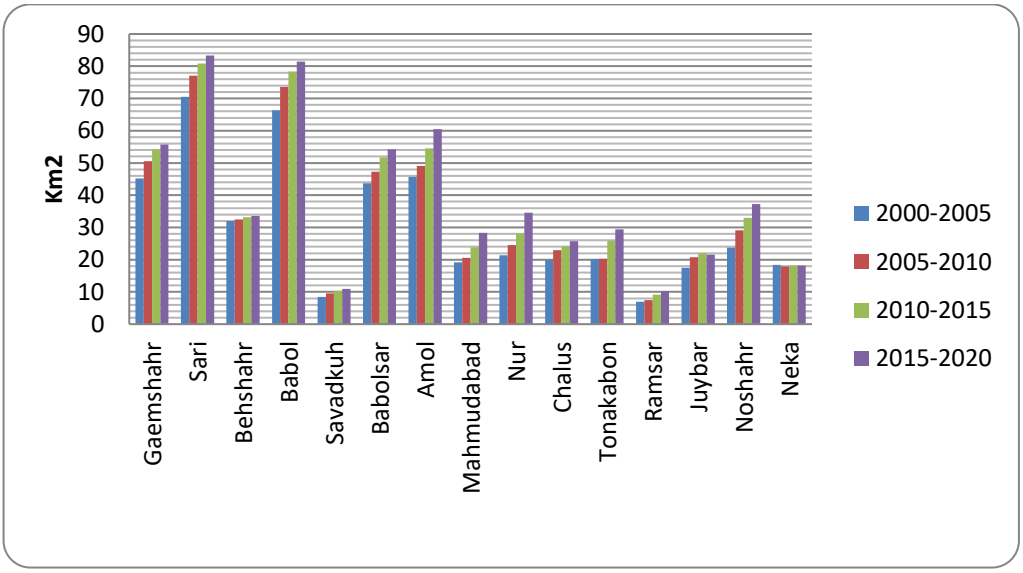


Figure 25 Built-up areas change over time in Mazandaran, Iran (2000-2020)

Expanding on the provided information, Figure 26 visually illustrates the trend of sprawl observed in Mazandaran from 2000 to 2020. This graphical representation effectively encapsulates the dynamic features of sprawl in the region, offering a comprehensive analysis of its progression over twenty years.

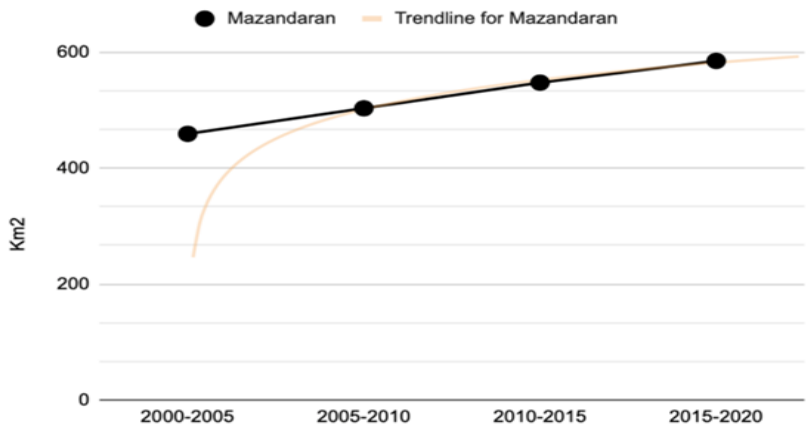


Figure 26 Total built-up (sprawl) trends areas in Mazandaran during 2000-2020

The statistical data extracted from remote sensing on the satellite images in Mazandaran offers numerical insights into the extent of sprawl across various cities. This data covers four 5-year intervals spanning from 2000 to 2020. The statistical information primarily measures the built-up area development within Mazandaran's counties. Importantly, these counties encompass many cities and villages, representing the extent of Urban Sprawl. The analysis incorporates Gaemshahr, Sari, Behshahr, Babol, Savadkuh, Babolsar, Amol, Mahmudabad, Nur, Chalus, Tonkabon, Ramsar, Juybar, Noshahr, and Neka counties.

The following findings are drawn from a closer examination of the data:

- **Analysis of trends:** Over the past 20 years, Sprawl has tended to rise in all cities and counties. This suggests that the region has had steady growth in built-up areas, a key element of sprawl.

- **The Rate of change** at which urban sprawl changes over time varies significantly between cities. Cities like Gaemshahr, Sari, and Babol, which serve as the center of Mazandaran's polycentric city-region, exhibit a considerably greater rate of increase in sprawl, indicating a more rapid rate of urbanization.

Cities like Savadkuh in the middle of the province and Ramsar, the latest city on the west side of the province, which have differentiated themselves from the Mazandaran region's dense polycentric structure, show a slower pace of growth, indicating a more gradual urban expansion.

- **Inter-city comparison:** Projections indicate that by 2020, Sari and Babol will experience the most pronounced levels of sprawl. This observation potentially signifies multiple factors, including a higher frequency of converting rural or undeveloped lands into built-up areas in these cities. Conversely, Savadkuh and Ramsar display the lowest sprawl metrics, indicating a lesser degree of urban development than their counterparts.

The information provided here offers a crucial insight into the extent and pace of urban sprawl within the Mazandaran region. Grasping these trends is imperative for facilitating sustainable development in the area, effectively managing urban expansion, and strategically planning infrastructure. A more in-depth exploration of the underlying factors driving these trends, such as population growth, economic progress, land use regulations, and transportation infrastructure, would be essential to gain a deeper comprehension.

5.6.2 Mazandaran's current mobility network situation

The transport network, especially the road infrastructure, holds paramount significance within every mobility system. Nevertheless, prevailing studies and scholarly resources on the present condition of Mazandaran's transportation framework, accessible through public databases, merely encompass a fraction of the entire network. Consequently, publicly accessible information on this topic remains restricted. The researcher adopted an innovative approach to generating the required data to address the research objectives comprehensively.

As detailed in the Methodology chapter, the researcher employed the Open Street Maps database resources as the primary data source, supplemented by satellite maps

obtained from Google-Earth Engine and Google-Earth. This amalgamation of data sources facilitated the generation of two distinctive datasets: one portraying the length and another depicting the area of Mazandaran's primary and secondary transport networks at the county level.

Table 5 Mazandaran counties primary mobility network Area (Km^2)

Counties	5-Years interval				
	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020
Abbas Abad	0,77	0,77	0,77	0,77	0,77
Amol	5,82	5,82	4,94	5,82	5,83
Babol	2,09	2,15	2,15	2,27	2,89
Babolsar	1,32	1,48	1,43	1,48	1,48
Behshahr	2,63	2,52	2,52	2,63	2,69
Chalus	3,30	3,30	3,23	4,03	4,12
Freydonkenar	0,41	0,41	0,40	0,70	0,70
Gaemshahr	1,84	1,84	1,85	1,87	1,90
Galogah	0,78	0,78	0,78	0,78	0,78
Joybar	0,73	0,72	0,73	0,73	0,73
Mahmudabad	1,63	1,63	1,74	1,84	2,23
Miandoroud	0,36	0,36	0,36	0,36	0,36
Neka	0,62	0,86	0,86	0,86	0,86
Northern Savadkoh	0,69	0,69	0,69	0,69	0,69
Noshahr	2,04	2,04	2,04	2,08	2,08
Nur	1,83	1,83	2,03	2,03	2,03

Ramsar	0,79	0,79	0,79	0,80	0,81
Sari	5,66	5,74	5,85	6,23	6,34
Savadkuh	2,63	2,63	2,63	2,63	2,63
Simorgh	0,68	0,68	0,68	0,68	0,68
Tonakabon	1,42	1,35	1,49	1,87	1,87
Mazandaran Counties Total Area (Km^2)	**38,03**	**38,39**	**37,96**	**41,11**	**42,44**

Table 6 Mazandaran counties primary mobility network length (Km)

Counties	**5-Years interval**				
	1995-2000	**2000-2005**	**2005-2010**	**2010-2015**	**2015-2020**
Abbas Abad	37,16	37,16	37,16	37,16	37,16
Amol	263,49	263,49	214,15	263,49	263,79
Babol	102,43	105,90	105,77	111,38	142,92
Babolsar	66,13	73,78	71,37	73,78	73,78
Behshahr	124,41	118,80	118,52	124,18	127,89
Chalus	141,86	141,96	135,71	178,53	182,87
Freydonkenar	20,68	20,68	20,39	35,51	35,50
Gaemshahr	90,48	90,48	91,21	91,73	93,66
Galogah	39,15	39,15	39,15	39,15	39,15
Joybar	33,77	33,75	33,86	33,85	33,85

Mahmudabad	79,94	79,94	85,38	91,05	108,60
Miandoroud	17,77	17,77	17,77	17,77	17,77
Neka	30,33	43,40	43,40	43,40	95,33
Northern Savadkoh	34,23	34,23	34,23	34,23	34,23
Noshahr	101,27	101,27	101,27	103,42	103,42
Nur	91,70	91,70	101,50	101,45	101,53
Ramsar	40,11	40,29	40,34	40,37	41,77
Sari	257,93	261,75	268,79	286,03	293,76
Savadkouh	123,12	123,12	123,12	123,12	123,12
Simorgh	31,62	31,62	31,62	31,62	31,62
Tonakabon	72,04	68,04	75,78	95,32	43,40
Mazandaran Counties' Primary Mobility Network Length (Km)	1274,80	1293,46	1.251	1380,08	1.491

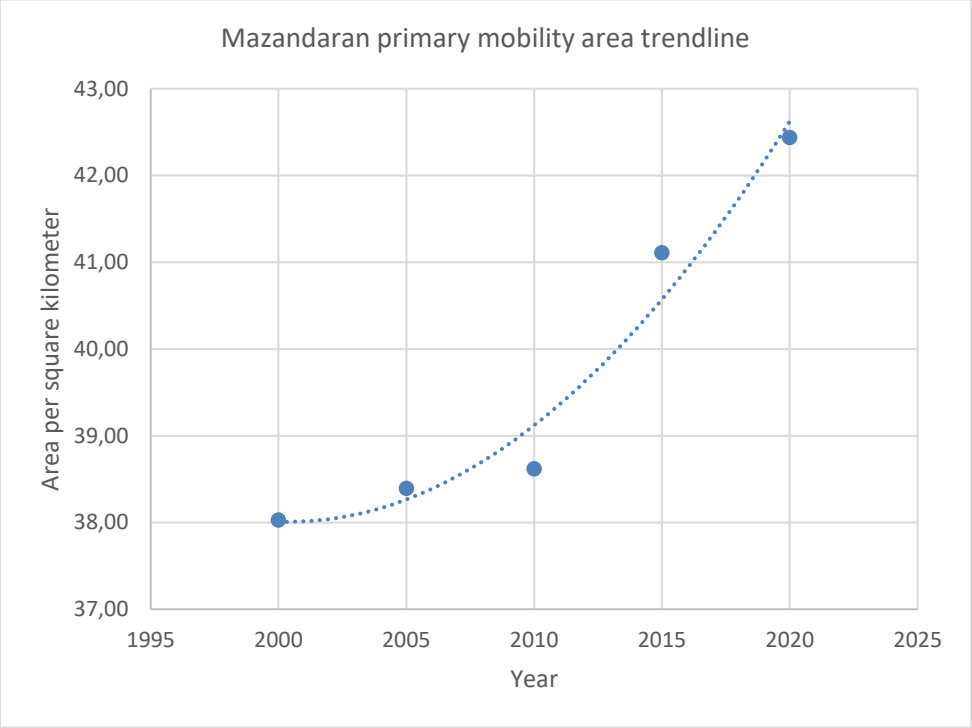


Figure 27 Trendline of the primary mobility area in Mazandaran during 2000-2020

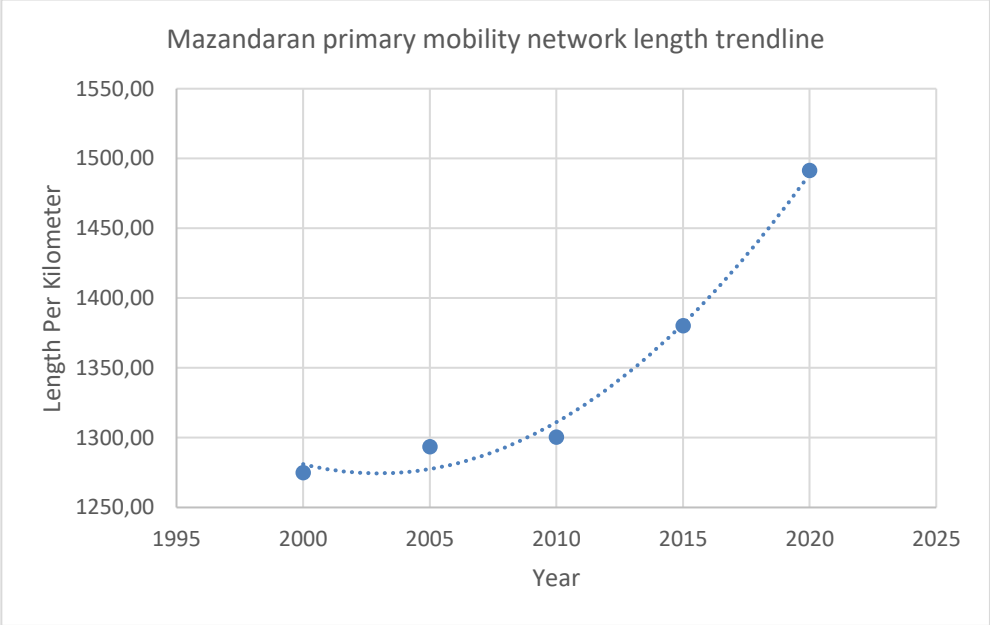
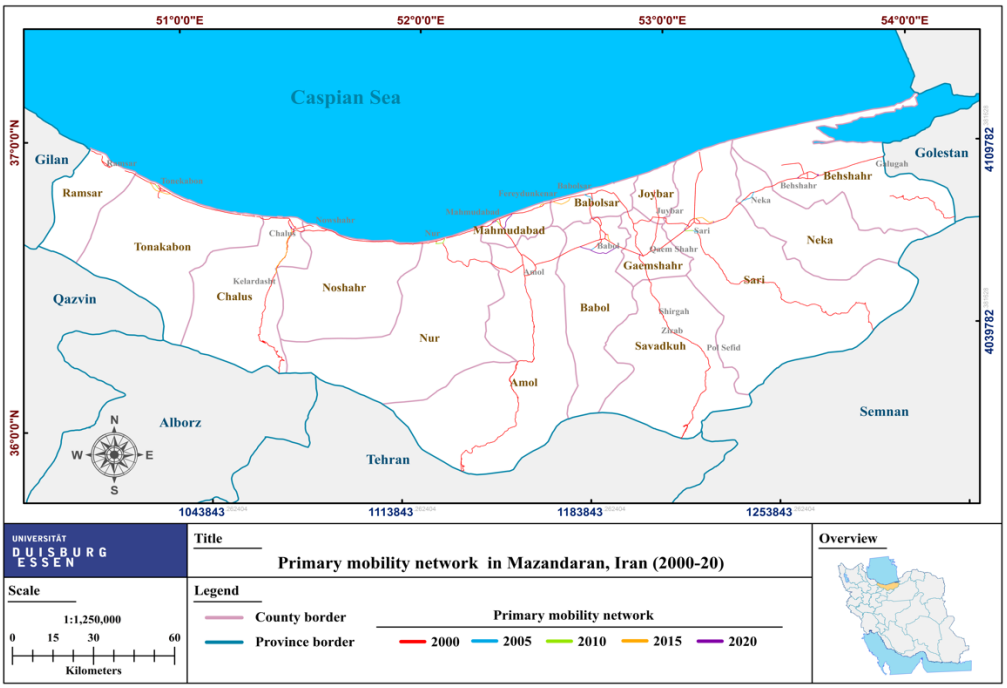
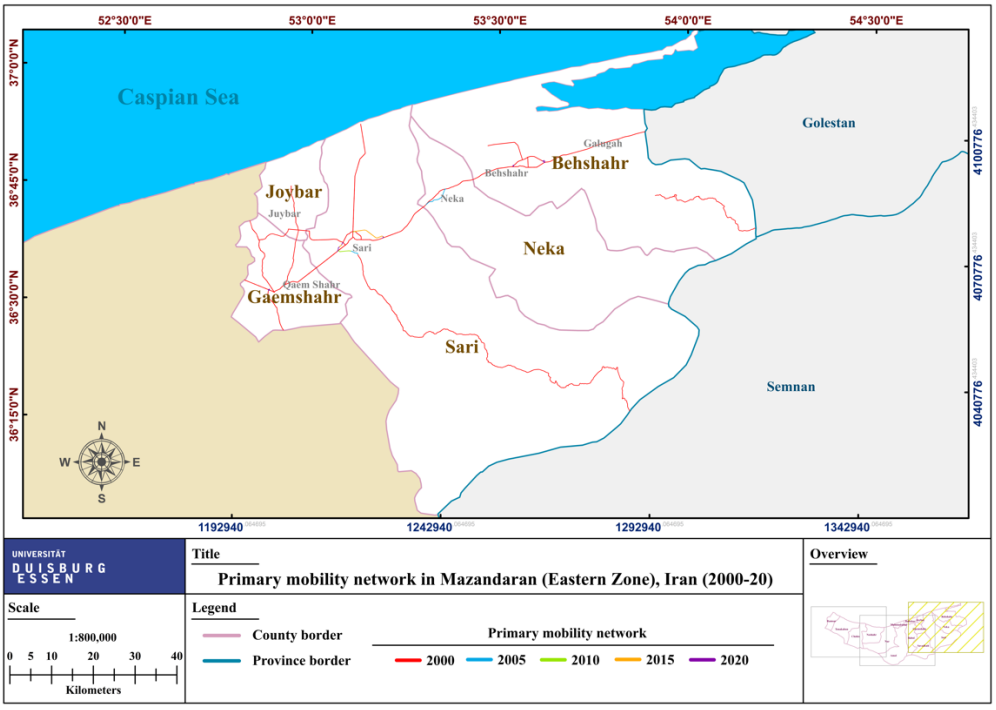


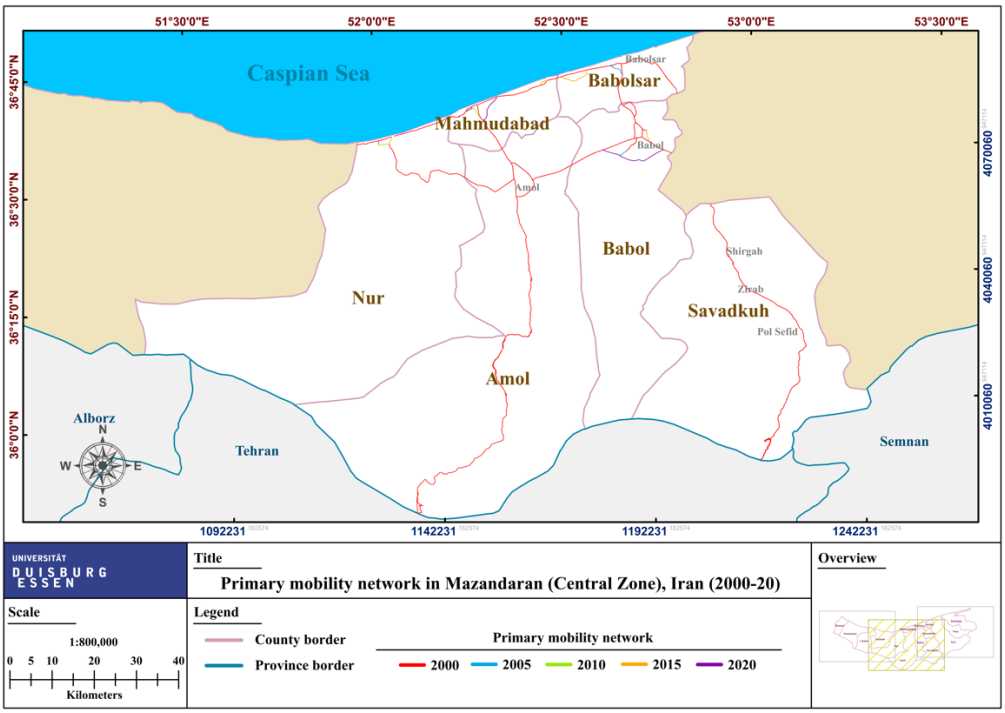
Figure 28 Trendline of the primary mobility length in Mazandaran during 2000-2020



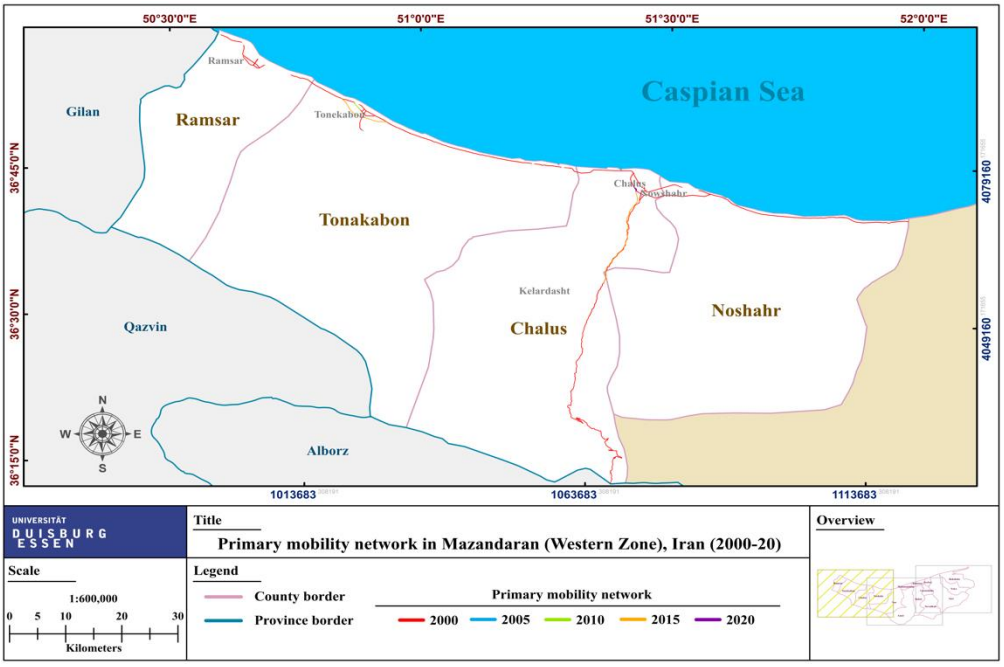
Map 19 Primary mobility network development in Mazandaran between years 2000-2020



Map 20 Primary mobility network development in Mazandaran between years 2000-2020 - Eastern Zone



Map 21 Primary mobility network development in Mazandaran between years 2000-2020 - Central Zone



Map 22 Primary mobility network development in Mazandaran between years 2000-2020 - Western Zone

Table 7 Mazandaran counties secondary mobility network area (Km^2)

Counties	5-Years interval				
	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020
Abbas Abad	0,65	0,71	0,71	0,71	0,71
Amol	2,17	2,35	2,45	2,78	2,83
Babol	3,71	4,07	4,08	4,31	4,35
Babolsar	0,93	1,01	1,02	1,03	1,04
Behshahr	2,04	2,27	2,42	2,85	2,86
Chalus	0,54	0,78	0,80	0,80	0,82
Freydonkenar	0,39	0,43	0,44	0,47	0,50
Gaemshahr	1,10	1,19	1,20	1,20	1,20
Galogah	1,06	1,18	1,18	1,18	1,18
Joybar	0,99	1,18	1,19	1,21	1,21
Kelardasht	0,55	0,60	0,60	0,60	0,60
Mahmudabad	0,36	0,40	0,40	0,40	0,40
Miandoroud	0,97	1,07	1,20	1,32	1,32
Neka	0,74	0,81	0,87	0,88	0,88
Northern Savadkoh	0,58	0,63	0,63	0,63	0,63
Noshahr	1,38	1,55	1,55	1,55	1,55

Nur	4,10	4,51	4,51	4,51	4,64
Ramsar	1,82	1,99	1,99	1,99	1,99
Sari	1,31	1,45	1,73	1,75	1,85
Simorgh	0,12	0,14	0,15	0,15	0,15
Tonakabon	1,39	1,52	1,52	1,52	1,53
Mazandaran counties secondary mobility network area (Km^2)	26,90	29,84	30,64	31,83	32,22

Table 8 Mazandaran counties secondary mobility network length (Km)

Counties	5-Years Interval				
	1995-2000	**2000-2005**	**2005-2010**	**2010-2015**	**2015-2020**
Abbas Abad	**35,35**	**35,35**	**35,35**	**35,35**	**35,35**
Amol	**123,35**	**130,45**	**148,15**	**148,15**	**151,23**
Babol	**214,09**	**217,12**	**231,07**	**231,07**	**233,34**
Babolsar	**51,73**	**52,55**	**52,70**	**52,70**	**53,64**
Behshahr	**103,78**	**116,00**	**142,69**	**142,69**	**143,11**
Chalus	**27,54**	**38,92**	**38,92**	**38,92**	**39,73**
Freydonkenar	**24,66**	**25,57**	**27,69**	**27,69**	**29,36**

Galogah	54,34	56,59	56,59	56,59	56,59
Ghaemshahr	63,71	63,81	63,81	63,81	63,81
Joybar	49,46	56,91	58,18	58,18	58,26
Kelardasht	31,64	31,64	31,64	31,64	31,64
Mahmudabad	18,38	18,38	18,38	18,38	18,40
Miandoroud	48,48	59,19	65,69	65,69	65,69
Neka	41,55	45,44	46,08	46,08	46,08
Northern Savadkoh	29,59	29,59	29,59	29,59	29,61
Noshahr	69,96	72,03	72,03	72,03	72,03
Nur	207,62	208,48	208,48	208,48	215,24
Ramsar	94,60	94,66	94,66	94,66	94,66
Sari	67,91	85,30	86,18	86,18	94,30
Simorgh	6,10	7,11	7,11	7,11	7,11
Tonekabon	73,33	73,33	73,33	73,33	73,65
Mazandaran Counties Total Secondary Access Length (Km)	1437,17	1518,41	1588,30	1588,30	1612,81

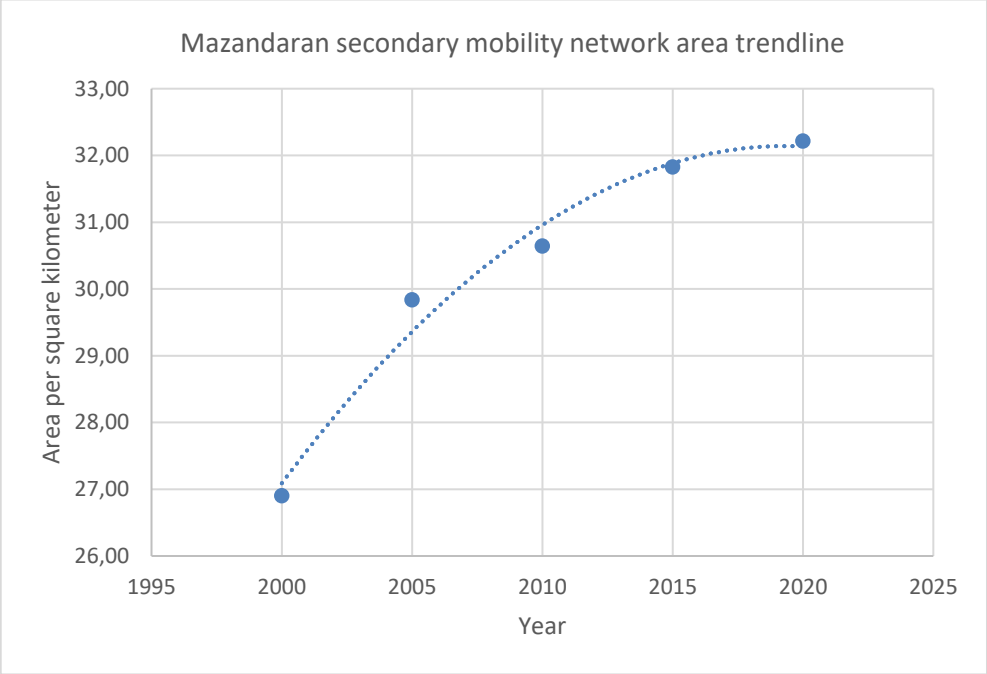


Figure 29 Trendline of the secondary mobility network area in Mazandaran during 2000-2020

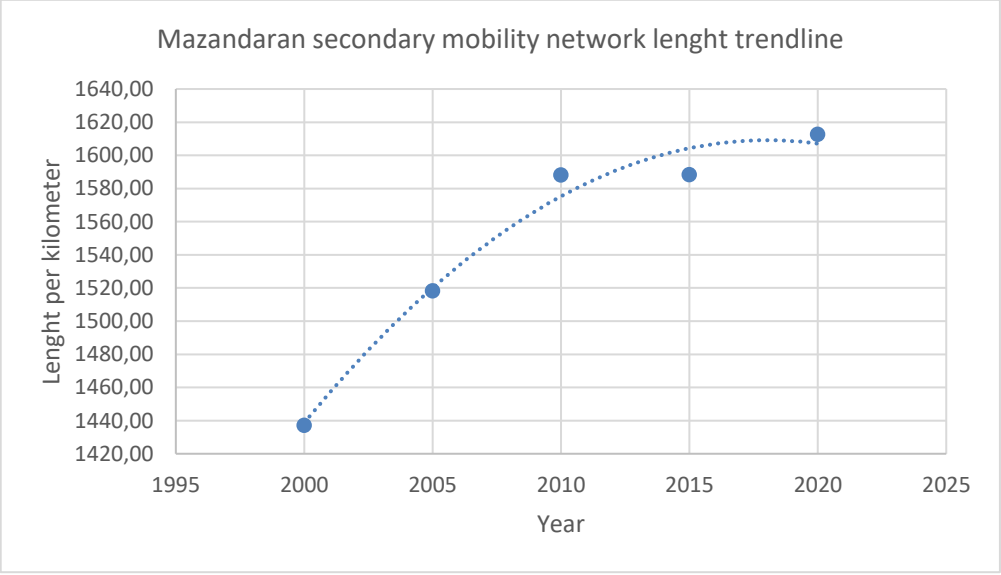
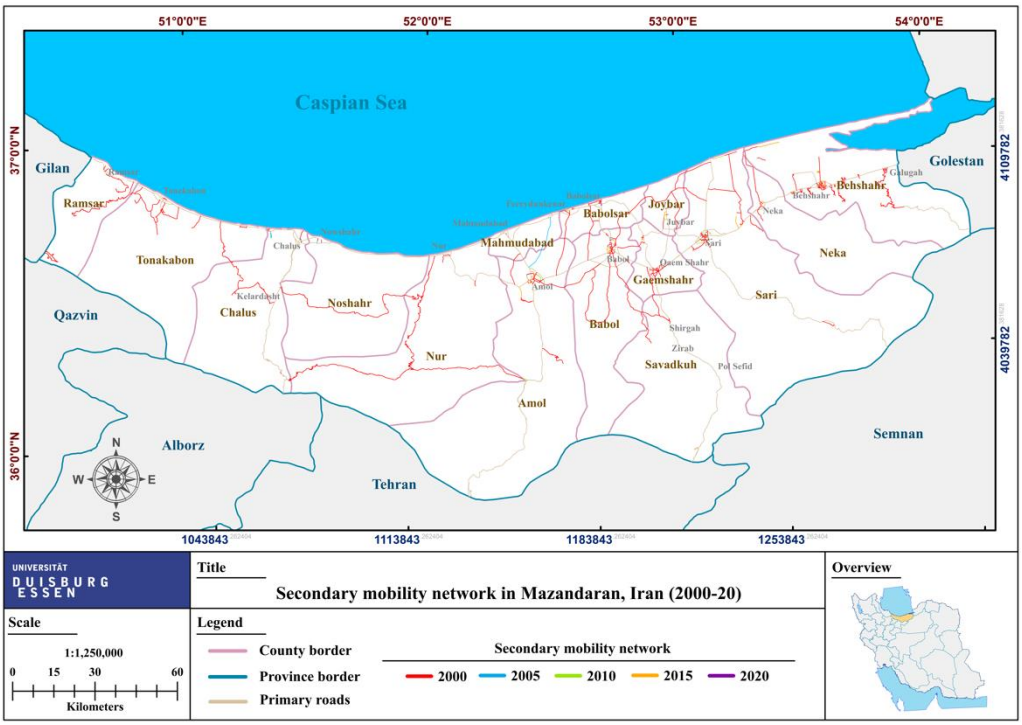
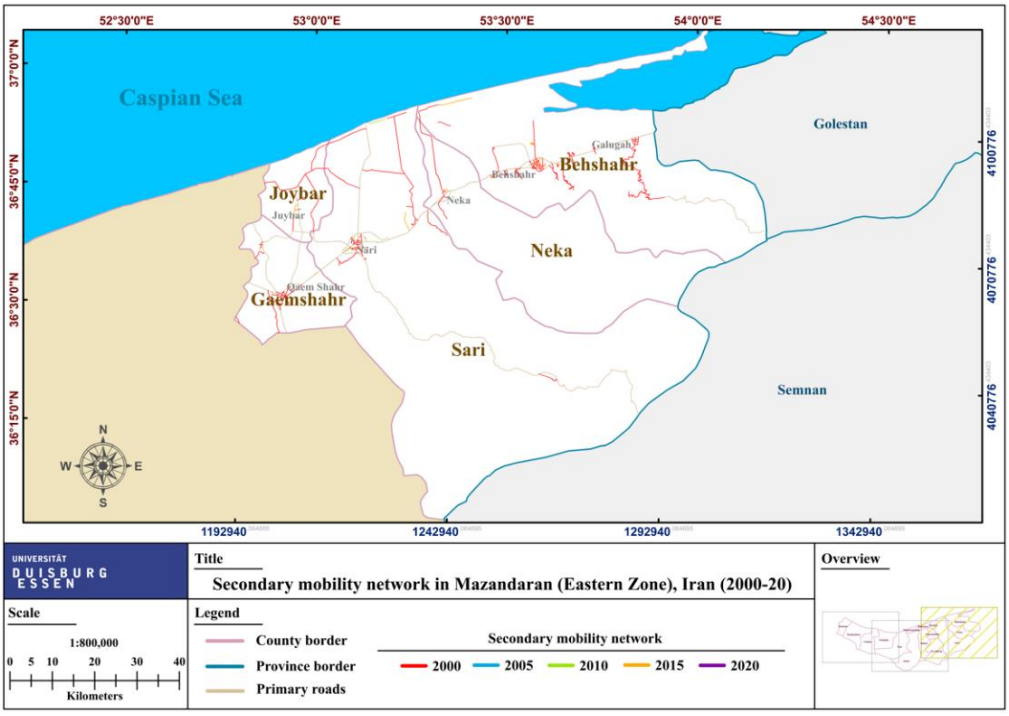


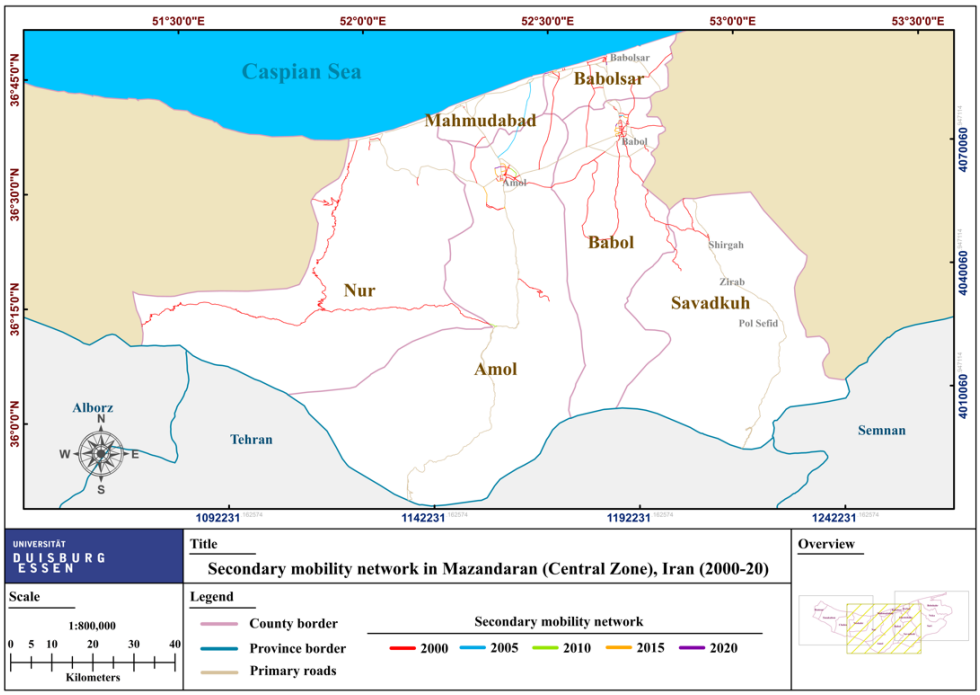
Figure 30 Mazandaran secondary mobility network length trendline



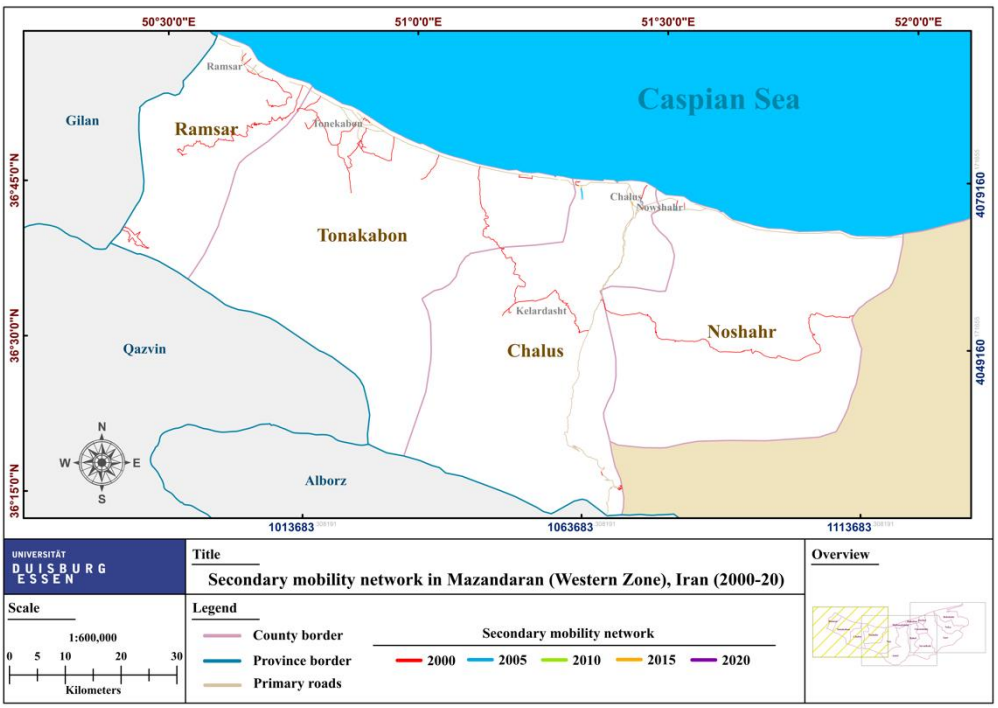
Map 23 Secondary mobility network development in Mazandaran between years 2000-2020



Map 24 Secondary mobility network development in Mazandaran between years 2000-2020 - Eastern Zone



Map 25 Secondary mobility network development in Mazandaran between years 2000-2020 - Central Zone.



Map 26 Secondary mobility network development in Mazandaran between years 2000-2020 - Western Zone

The following observations can be made based on data obtained from Mazandaran's mobility networks:

- **Primary mobility network area:** From 1995 to 2020, the total primary mobility network area for all Mazandaran counties expanded from 38.03 Km^2 in 1995-2000 to 42.44 Km^2 in 2015-2020. This illustrates the gradual expansion of the major mobility network infrastructure.
- **Primary mobility network length:** According to the presented data for the period 1995-2020, the length in kilometers (Km) of the primary mobility network in different counties of Mazandaran increased from 1274.80 Km in 1995-2000 to 1491 Km in 2015-2020, with the total length of the primary mobility network for all counties in Mazandaran increasing from 1274.80 Km in 1995-2000 to 1491 Km in 2015-2020. The primary mobility network infrastructure in the area is likely to be expanding and developing considering this.
- **Secondary mobility network area:** According to the statistics and values presented in the area in Km^2 of the secondary mobility network in various counties of Mazandaran, the total secondary mobility network area for all counties increased from 26.90 Km^2 in 1995-2000 to 32.22 Km^2 in 2015-2020. This also demonstrates the expansion of Mazandaran's secondary mobility network infrastructure.
- **Secondary mobility network length:** Data on the length of the secondary mobility network in kilometers (Km) in different counties of Mazandaran during five-year intervals is supplied. The overall length of all counties' secondary mobility network expanded from 1437.17 Km in 1995-2000 to 1612.81 Km in 2015-2020. This implies expanding and developing the region's secondary mobility network infrastructure.

The findings reveal a noticeable growth in Mazandaran's primary and secondary mobility networks. The growth in network area and length can be attributed to various

factors. These factors can include a response to the growing demand for mobility and accessibility among the citizens of Mazandaran, the emergence of urban and human settlements in the region, and a deliberate focus on enhancing regional transit infrastructure and connectivity.

5.7 Economic and social variable

To understand the situation of sustainable development in Mazandaran province, it is imperative to draw upon statistical data from various categories. Even though the Iranian national statistics organization releases annual statistical reports, the fragmented structure of government agencies responsible for statistics often poses challenges in accessing comprehensive data crucial for Iran's sustainable development initiatives. The present research tackles this issue by incorporating vital statistical data from diverse publicly accessible sources. Significantly, the study emphasizes using public data from the Ministry of Road and Urban Development of Iran—tables 9 and 10 present socioeconomic factors encompassing employment and urban population characteristics. Tables 11 and 12 also present economic indicators illustrating freight and package postal shipping escalation.

Table 9 Number of employment in Mazandaran regions' counties during 1995-2015
(Source: Iran National Statistics Book, 2015)

County / Year	Employment 1	Employment 2	Employment 3	Employment 4
	1995-2005	2005-2010	2010-2015	2015-2020
Gaemshahr	76064	103482	113866	114460
Sari	104286	152855	164053	162408
Behshahr	37788	40373	55182	56678
Babol	109782	152639	158276	158642
Savadkuh	13883	15381	18992	16543
Babolsar	39763	59075	57278	39022
Amol	83248	112902	118604	126033

Mahmudabad	21711	27502	30881	30659
Nur	23325	30923	32956	34983
Chalus	27074	37419	35861	41705
Tonakabon	41821	64053	62494	64170
Ramsar	16125	21385	22234	22999
Noshahr	27074	38361	40176	41411
Neka	24312	33295	34778	36023

Table 10 Population of Mazandaran regions' counties during 1995-2015
(Source: Iran National Statistics Book, 2015)

County / Year	**Urban Population 1**	**Urban Population 2**	**Urban Population 3**	**Urban Population 4**
	1995-2005	**2005-2010**	**2010-2015**	**2015-2020**
Gaemshahr	171514	211401	234924	258486
Sari	199664	273972	308456	323737
Behshahr	99300	124378	130570	138772
Babol	179626	240073	261733	305578
Savadkuh	30403	36691	32390	34349
Babolsar	66620	94937	98176	113915
Amol	160429	202369	222066	246355
Mahmudabad	20054	34368	37692	38543

Nur	27165	46569	48531	54281
Chalus	44000	64726	62792	95693
Tonakabon	70960	86153	96702	114152
Ramsar	45193	50040	51256	56713
Noshahr	44000	42175	46184	55673
Neka	35208	46291	50680	60991

Table 11 Number of incoming and outcoming parcels in Mazandaran regions' counties during 1995-2020 (Source: Iran National Statistics Book, 2020)

County / Year	**Incoming and outcoming Parcels 1**	**Incoming and outcoming Parcels 2**	**Incoming and outcoming Parcels 3**	**Incoming and outcoming Parcels 4**
	1995-2005	**2005-2010**	**2010-2015**	**2015-2020**
Gaemshahr	972508	5980241	10221725	11243897
Sari	2341330	9398405	11685278	12853805
Behshahr	439961	2280136	3346268	3680895
Babol	893974	4769646,5	9163280	10079608
Savadkuh	175126	689752	1717866	1889653
Babolsar	588235	2271439	4534082	4987490
Amol	508274	3979337	7124135	7836548
Mahmudabad	121590	1151589,5	1957659	2153424
Nur	219882	1702981,5	3692500	4061750

Chalus	184288	2009026	2847564	3132320
Tonakabon	489370	3622277,5	4599530	5059483
Ramsar	554318	1205545	1648605	1813466
Noshahr	184288	1600355	2712780	2984058
Neka	158011	1231354	1799218	1979140

Table 12 Volumes of displaced commodity in Mazandaran regions' counties per tons during 1995-2015 (Source: Iran National Statistics Book, 2015)

County / Year	**Displaced Commodity per ton 1**	**Displaced Commodity per ton 2**	**Displaced Commodity per ton 3**	**Displaced Commodity per ton 4**
	1995-2005	**2005-2010**	**2010-2015**	**2015-2020**
Gaemshahr	78479	156957	113881	142105
Sari	661167	1322333	1332890	1365345
Behshahr	138834	277667	182674	487751
Babol	60764	121527	126955	46839
Savadkuh	241120	482239	431474	501259
Babolsar	31047	62094	47624	55063
Amol	616806	1233612	1394641	943742
Mahmudabad	2285	4569	5188	10463
Nur	21742	43484	21134	11089

Chalus	74390	148780	402949	143543
Tonakabon	10237	20474	27940	42021
Ramsar	1533	3066	2576	4109
Noshahr	45371	90741	125978	119760
Neka	386278	772556	2429261	1677078

5.8 Statistical analysis and thematic data overview

The statistical data in this study has been categorized into six overarching sections, representing standardized averages for specific periods across various cities in Mazandaran province. These categories are as follows:

- Built-up area (sprawl) growth.
- Increase in the mobility network development.
- Urban growth in terms of population
- Employment growth.
- Growth of commodity displaced.
- Growth of (parcels) postal shipping.

Using the SPSS software, a Pearson correlation coefficient analysis was conducted to examine the connections between the mobility system in the Mazandaran polycentric city-region and specific variables associated with sustainable development across the periods from 1995 to 2020. The outcomes of this analysis are detailed below.

Table 13 Pearson correlation coefficient between the two variables of primary and secondary mobility network length and built-up area during the years 1995-2020

Pearson correlation coefficient	Target years in 5-years Intervals			
	1995-2005	2005-2010	2010-2015	2015-2020
Primary mobility network length and built-up area	0.038	0.035	0.034	0.023
Secondary mobility network length and built-up	**0.456**	**0.51**	**0.52**	**0.54**

Table 14 Pearson correlation coefficient between two variables of primary and secondary mobility network length and employment during the years 1995-2020

Pearson correlation coefficient	Target years in 5-years Intervals			
	1995-2005	2005-2010	2010-2015	2015-2020
Primary mobility network length and employment	0.61	0.61	0.63	0.69
Secondary mobility network length and employment	**0.51**	**0.57**	**0.57**	**0.59**

Table 15 Pearson correlation coefficient between two variables of primary and secondary mobility network length and incoming and outgoing parcels during the years 1995-2020

Pearson correlation coefficient	Target years in 5-years Intervals			
	1995-2005	2005-2010	2010-2015	2015-2020
Primary mobility network length and incoming and outgoing parcels	0.56	0.69	0.66	0.67
Secondary mobility network length and incoming and outgoing parcels	**0.29**	**0.44**	**0.55**	**0.56**

Table 16 Pearson correlation coefficient between the two variables of primary and secondary mobility network length and the average commodity displaced by public vehicles during the years 1995-2020

Pearson correlation coefficient	Target years in 5-years Intervals			
	1995-2005	2005-2010	2010-2015	2015-2020
Primary mobility network length and commodity displaced	0.74	0.74	0.21	0.35
Secondary mobility network length and commodity displaced	**-0.02**	**0.06**	**-0.15**	**-0.05**

Table 17 Pearson correlation coefficient between two variables of primary and secondary mobility network length and urban population during the years 1995-2020

Pearson correlation coefficient	Target years in 5-years Intervals			
	1995-2005	2005-2010	2010-2015	2015-2020
Primary mobility network length and population	0.68	0.69	0.68	0.70
Secondary mobility network length and population	**0.49**	**0.57**	**0.59**	**0.60**

Correlation analysis and Interpretation data analysis coefficients between the target variables:

As discussed in the research methods chapters, Pearson's correlation coefficient is an instrument for determining the strength and direction of the link between two continuous variables.

- A correlation coefficient of one indicates that for every positive rise in one variable, there is a fixed proportional increase in the other.

- A correlation coefficient of -1 indicates that for every positive rise in one variable, there is a fixed proportional reduction in the other.

- Zero signifies that there is no positive or negative growth for every variable increase; both variables are unrelated and have no relation between them.

The interpretation of the correlation coefficients for each pair of variables in the research during the respective time duration between 1995-2020 is as follows:

- **Primary mobility network development and sprawl growth:** The correlation between the development of the Primary Mobility Network and the expansion of Sprawl continues to be minimal across all periods. This observation suggests that these two variables do not possess a substantial linear relationship, and this relationship has slightly diminished over time.

- **Secondary mobility network development and sprawl growth:** The correlation between these variables remains weak to moderate across all periods, suggesting a somewhat favorable connection. This trend is characterized by a slight increase in correlation from 1995-2005 to 2005-2010, a relatively stable correlation from 2005-2010 to 2010-2015, and another slight increase from 2010-2015 to 2015-2020. Notably, there is an observable tendency for Sprawl expansion to align with the progression of the Secondary Mobility Network.

- **Primary mobility network development and number of employments:** The growth of the primary mobility network and the number of employers exhibit a moderate correlation across all periods, highlighting a relatively robust positive connection. This association remained consistent from 1995-2005 to 2005-2010, followed by an increase from 2005-2010 to 2010-2015 and another rise from 2010-2015 to 2015-2020. Notably, as the primary mobility network expands, employers have concurrently increased.

- **Secondary mobility network development and employment number:** The correlation exhibits moderate strength Across all time periods, indicating a moderately robust positive connection. Notably, the development of the

secondary mobility network and the number of employers experienced significant growth from 1995-2005 to 2005-2010, followed by a period of stability from 2005-2010 to 2010-2015 and a slight increase from 2010-2015 to 2015-2020. This trend underscores the relationship where an expansion in the secondary mobility network coincides with increased employers.

- **Primary mobility network development and postal parcels:** The connection between the development of the primary mobility network and incoming and outgoing postal parcels demonstrates moderate strength across all periods, indicating a relatively robust positive relationship. The correlation between primary mobility network development and postal outlets exhibited significant growth from 1995-2005 to 2005-2010, a decline from 2005-2010 to 2010-2015, and a slight increase from 2010-2015 to 2015-2020. This underscores the trend where the growth of the primary mobility network corresponds with an increase in the number of postal outlets.

- **Secondary mobility network development and postal parcels:** The connection appears relatively weak to moderate across all periods, suggesting a somewhat favorable relationship. The correlation between secondary mobility network development and the number of postal parcels experienced a notable increase from 1995-2005 to 2005-2010, followed by another increase from 2005-2010 to 2010-2015, and a minor rise from 2010-2015 to 2015-2020. There is a tendency for the volume of posted letters to rise in line with the development of the secondary mobility network.

- **Primary mobility network development and volume of commodity displaced:** The correlation is notable from 1995 to 2005 and 2005 to 2010, but it diminishes to an extremely weak level from 2010 to 2015 and 2015 to

2020, respectively. This trend indicates that the relationship between these two variables has weakened over time.

- **Secondary mobility network development and volume of commodity displaced:** The correlation is consistently low or very weakly negative across all periods, indicating the absence of a significant linear relationship between these two variables. Specifically, the development of the secondary mobility network and the number of commodities displaced displayed an increase from 1995 to 2005, a notable decline from 2005 to 2010, and another increase from 2010 to 2015.

- **Primary mobility network development and population density:** The relationship between primary mobility network development and population exhibits a consistently moderate strength across all periods, highlighting a notably significant positive connection. Specifically, the association between primary mobility network development and population density observed a slight increase from 1995-2005 to 2005-2010, followed by a minor decrease from 2005-2010 to 2010-2015, and a subsequent slight increase from 2010-2015 to 2015-2020. There is a tendency for population density to expand alongside the progression of the primary mobility network.

- **Secondary mobility network development and population:** The correlation displays a consistent weak to moderate strength across all periods, suggesting a moderately positive relationship. Notably, this connection experienced a slight increase between 1995 and 2005, remained steady from 2005 to 2010, and saw a marginal increase from 2010 to 2015. This

emphasizes the trend where the growth of the secondary mobility network corresponds with an increase in population density.

6 Result and Summary

Drawing from the research inquiries and hypotheses articulated within the study's conceptual framework, as detailed in the methodology section, the primary objective of this investigation was to intricately explore the interrelations among three crucial dimensions of sustainable development in the polycentric region: Environmental, economic, and social. Specifically, the study aimed to investigate the interaction dynamics of these dimensions within the context of the mobility system operating within a polycentric region. This endeavor was carried out systematically, analyzing the amassed dataset and extracting valuable insights.

This complex interplay becomes particularly evident when considering the specific correlations determined across diverse temporal intervals within the Mazandaran province. The study has successfully unveiled compelling trends and patterns by meticulously examining variables encompassing built-up area growth, mobility network development, urban population growth, employment growth, commodity displaced, and parcel shipping within Mazandaran.

The outcomes conspicuously reveal that the development of both primary and secondary mobility networks manifests diverse degrees of affiliation with the dimensions of sustainable development. Notably, the correlation coefficients illustrating the interrelation between these mobility networks and factors such as employment, postal parcels, population density, and even sprawl growth have provided profound insights into the dynamic relationships binding urban mobility infrastructure with pivotal markers of sustainability.

In the context of the environmental dimension, the data implies a noticeable connection between mobility networks and elements of sustainable development. This understanding underscores the multifaceted relationship that binds mobility systems with environmental considerations within a polycentric region.

Economically, the study highlights a significant positive correlation between the development of primary and secondary mobility networks and employment growth. Expanding mobility networks may potentially yield favorable repercussions for employment opportunities. Furthermore, the established linkages between mobility network development and factors such as commodity displaced within the province and parcel shipping underscore the pivotal role of robust mobility infrastructure in facilitating economic activities.

From a social standpoint, the study unveils patterns in the correlations between developments in mobility networks and the growth of the urban population. This intimates that the augmentation of mobility networks could play a pivotal role in accommodating population expansion and augmenting regional accessibility.

The findings from this inquiry underscore the complicated and multifaceted interconnections between sustainable development's environmental, economic, and social dimensions and the mobility system operative within a polycentric region. These insights significantly contribute to a more comprehensive comprehension of how urban mobility infrastructure can exert influence on and be influenced by diverse facets of sustainability. The outcomes of this analysis guide policymakers and urban planners within developing countries and, mainly, Mazandaran province, empowering them to make well-informed decisions that harmonize with the region's aspirations for sustainable development.

The subsequent sections will delve into an in-depth discussion of the findings and elements comprising the research investigation.

6.1 Sprawl in Mazandaran

To understand the complexities of the urban sprawl phenomenon, a holistic analysis is critical, delving deeply into the multifaceted factors underpinning its emergence.

In the specific context of this exploration, the extent of the built-up area by impermeable surfaces, including materials like asphalt and concrete, emerges as a straightforward yet revealing metric. This metric proves invaluable in assessing and delineating the developed zones within a given geographical region. The application of built-up area as a dependable and relatively precise statistical measure has sparked diverse interpretations of sprawl. This sheds light on and underscores the complicated nature of sprawl, characterized by the relentless and widespread expansion of urban and rural built-up areas.

In alignment with this interpretive framework, the present study undertakes an in-depth examination of the transformative dynamics within the built-up areas of Mazandaran's cities over two decades. This endeavor is undertaken with meticulous adherence to the methodologies developed in the preceding sections, ensuring consistency in the analytical process. The following table, a visual representation of data, vividly explains the ever-shifting patterns in the built-up landscape across Mazandaran province, including its various constituent cities. The following data highlights a persistent and gradual expansion trend in sprawl in Mazandaran, spanning five-year intervals commencing from 2000 and culminating in 2020.

This detailed quantitative inquiry provides a comprehensive depiction of the mounting sprawl and substantiates the enduring course of urban expansion within the geographic confines of Mazandaran province.

The subsequent trend line (Figures 31 and 32, see page 217), precisely derived from remote sensing analyses, visually represents the growth trend of built-up areas within Mazandaran province. Particularly noteworthy is the principal and continuous expansion that has characterized the province's landscape since 2005.

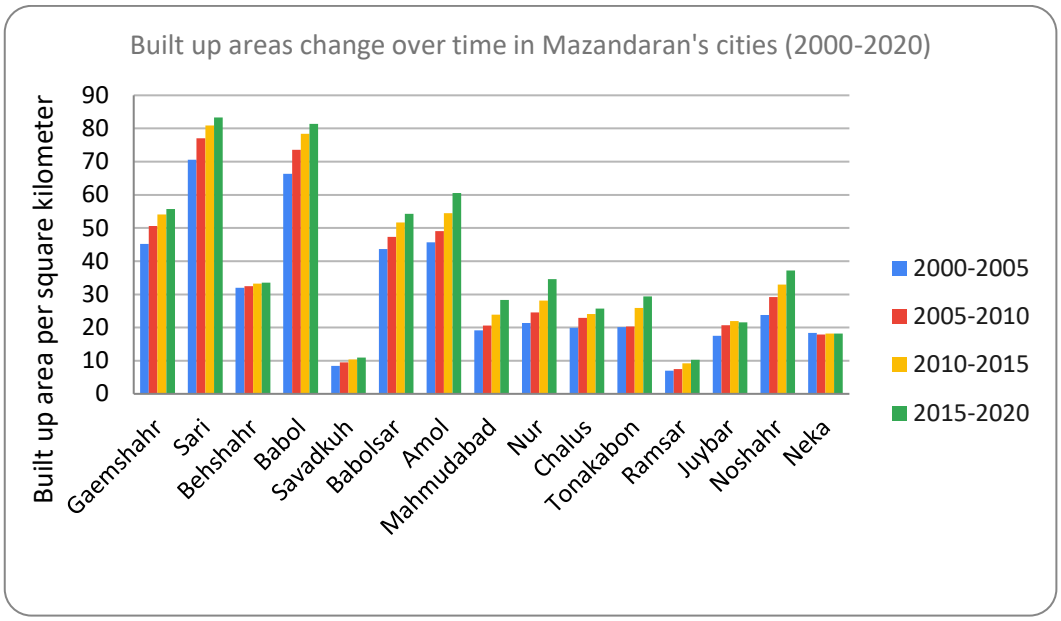


Figure 31 Built-up areas change over time in Mazandaran's cities for the years 2000-2020

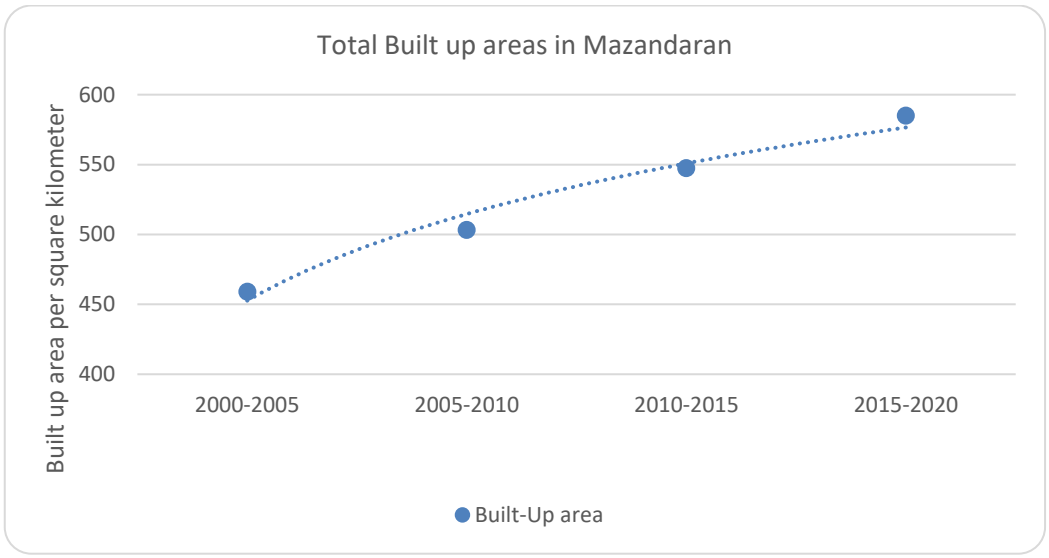


Figure 32 Built-up areas change over time in Mazandaran province for rural and urban areas.

This concrete trend is further validated by the detailed calculations that quantify urban sprawl, essentially measuring the amplification of built-up spaces, a trend transcending urban and rural domains across the province. The geography and spatial layout of

Mazandaran province unveils important factors that underlie the process of urban sprawl as follows:

- The eastern and central regions are particularly notable for their significant urbanization and urban sprawl. However, the coastal and western areas also exhibit notable levels of built-up area and, consequently, sprawl.

- The precise calculations derived from this comprehensive examination clearly emphasize the continuous expansion and spatial growth embracing the province's metropolitan and non-metropolitan regions.

- The comprehensive dataset presented here offers compelling evidence regarding the dynamic transformation of the urban environment in Mazandaran concerning the growth of built-up areas and urban sprawl.

- According to the statistical data obtained from remote sensing analyses in the central region of the province, which represents a significant part of the inhabited territory of the province and forms the backbone of the polycentric structure of the province, including the cities of Sari, Qaemshahr, Amol and Babol, the highest amount of increase in built-up area and urban sprawl has occurred.

- Also, the central region of Mazandaran effectively forms the core of human settlements in the province. In the time frame of this research, during the years 1995-2020, in the central region of Mazandaran, a significant convergence between urban and rural areas in terms of physical layout and urban fabric has been observed within the limits of the cities and in this sense, the author believes, this convergence is on the way to creating a comprehensive urban complex or forming a polycentric metropolitan area.

- Along the province's coastal zones, urban centers and residential districts are undergoing rapid expansion in their constructed areas. This growth trend is

particularly pronounced along the province's western coastline. Initial research findings suggest that these urban areas are undergoing an elevated degree of spatial integration. This progression unfolds sequentially. Firstly, establishing a polycentric structure is achieved through reducing distances between urban hubs and service centers. Subsequently, this process contributes to the development of constructed spaces and a subsequent increase in urban sprawl, ultimately playing a central role in this dynamic.

6.2 Mobility network

To acquire current data regarding the primary and secondary mobility networks in Mazandaran, the author has conducted a thorough assessment of the existing mobility infrastructure. This assessment relies on precise calculations and the systematic analysis of satellite imagery spanning from 2000 to 2020. The analytical results derived from this effort provide an extensive insight into the factors influencing the province's mobility environment. In this context, the key findings are as follows:

- The trajectory of the primary mobility network in Mazandaran province has unfolded with distinct patterns. Between 2000 and 2010, the primary mobility network witnessed steady and consistent growth, signifying a proactive developmental phase. Subsequently, the years' post-2010 showed a notable wave in its expansion, underscoring a substantial development in network proliferation and coverage.

- Shifting the focus to the secondary mobility network, a different evolution becomes evident. The phases between 2000 and 2005 were characterized by notable and substantial advancements in the secondary mobility network, clearly reflecting determined and concentrated development efforts. Following this initial phase, the network's growth trajectory has been characterized by a more gradual pace since 2005, a trajectory that is projected to continue through 2020.

- This analysis underscores the evolution of the mobility network in Mazandaran, effectively capturing the dynamic interplay between temporal phases and varying expansion rates for both primary and secondary mobility networks. This understanding is pivotal for devising informed strategies to enhance the province's mobility infrastructure.

Figures 33 and 34 visually represent the trends in the development of the Mazandaran province's primary and secondary mobility networks. The depicted trends unveil a coherent record, showcasing distinct growth phases within the specified time frames.

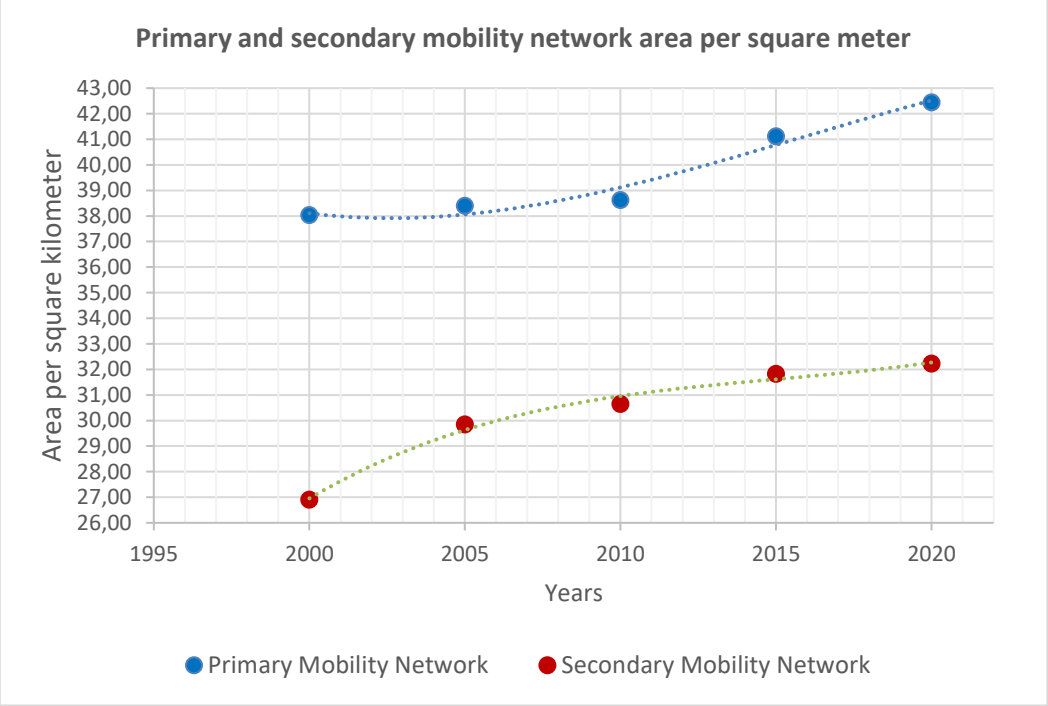


Figure 33 Trendline of the primary and secondary mobility network area in Mazandaran during 2000-2020

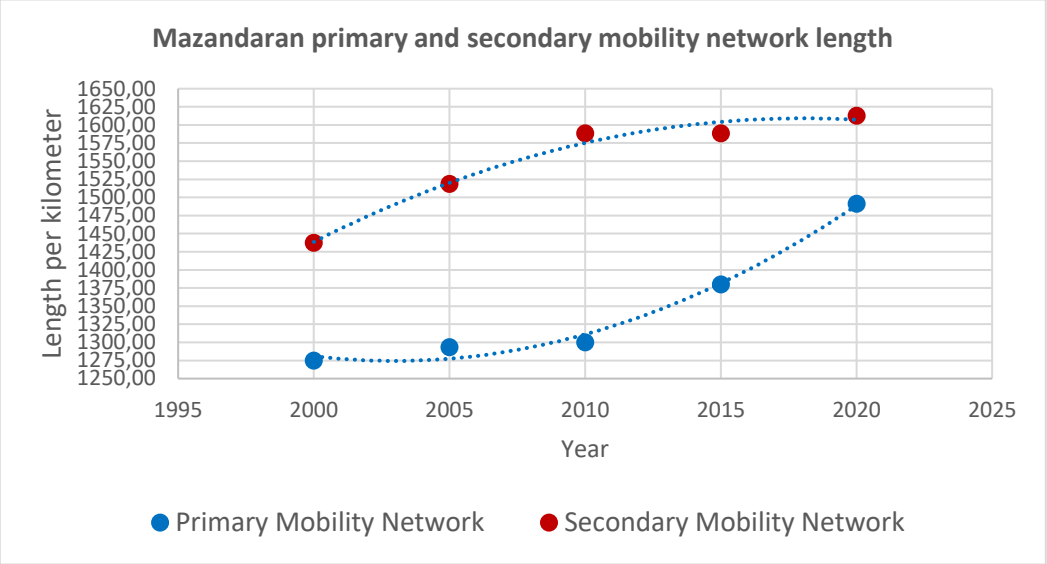


Figure 34 Trendline of the primary and secondary mobility network length in Mazandaran during 2000-2020

- The chart unveils a consistent and upward trajectory spanning from 2000 to 2010 for the primary mobility network. This initial phase is characterized by steady expansion, expressive of conscious efforts to enhance the province's foundational mobility infrastructure.
- The following period, spanning from 2010 to 2020, guides a new phase of development characterized by significant and consistent growth. This period signifies a remarkable leap in the scale and coverage of the primary mobility network.
- Turning attention to the secondary mobility network, the chart reveals a similar pattern but with undersized features. The period encompassing 2000 to 2010 emerged as a significant period of expansion, during which the secondary mobility network experienced substantial growth. Post-2010, the growth trajectory maintains acceleration, albeit at a more consistent rate, spanning until 2020. This phase is distinguished by its stability, implying a well-structured and controlled augmentation of the secondary mobility network.

6.3 Mobility and environmental aspects of sustainable development

The statistical investigation uncovers a compelling correlation between Mazandaran's transportation system and the province's environmental structure.

- For the time intervals of 2000-2005, 2005-2010, 2010-2015, and 2015-2020, the Pearson correlation coefficient, as presented in tables 11-12 (see pages 206 and 207) and tables 13-14 (see pages 209), offers clear evidence of a relationship between the primary mobility network length and the built-up area. Notably, the results indicate a significant and robust association between the length of the primary mobility network and the extent of the built-up area from 2000 to 2020. This relationship holds moderate intensity, marking the evolving connection between these pivotal factors.
- Furthermore, results derived from the Pearson correlation analysis between the secondary mobility network length and the built-up area, as illustrated in table 13 (see page 209), substantiate the interrelation of the studied variables.
- Examining the Pearson coefficient outcomes from 2000 to 2020, a clear inference emerges: a substantial correlation exists between the length of the secondary transportation network and the extent of built-up areas in Mazandaran. This finding reinforces that the secondary mobility network's expansion aligns with urban areas' growth.

Figure 35 (see page 223) illustrates the influence of Mazandaran's mobility system, comprising both primary and secondary mobility networks, on the environmental aspects investigated within this research framework. This visual representation

reinforces the complex relationship between transportation expansion and the province's changing environmental conditions.

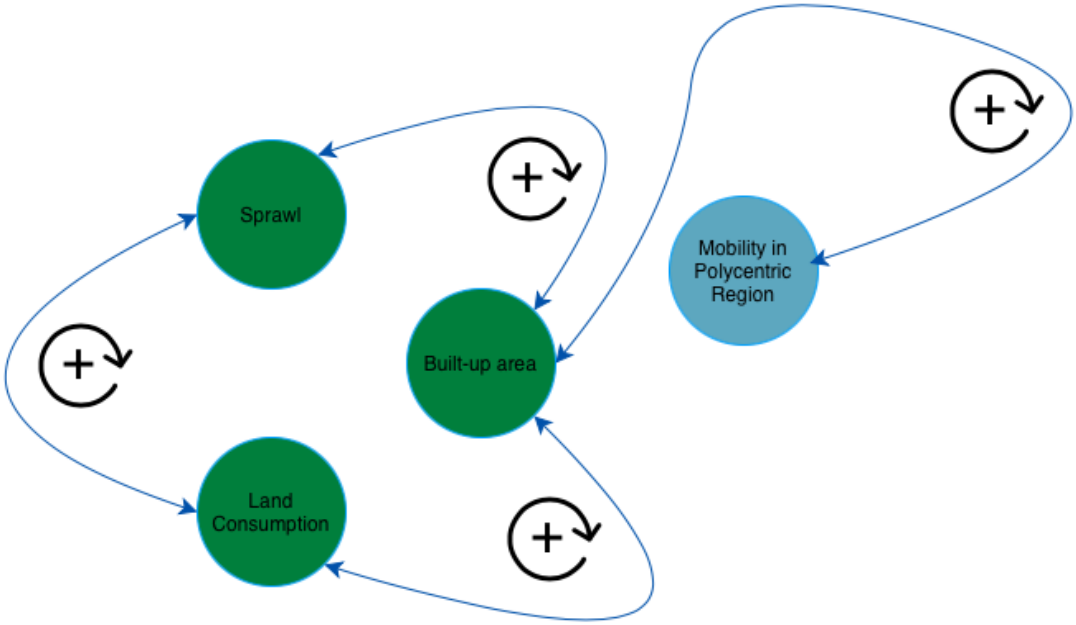


Figure 35 Mobility and built-up area relationship

- The rigorous statistical analysis conducted to explore the relationship between Mazandaran's mobility system, specifically the Primary and Secondary mobility networks, and the expansion of the built-up area has unveiled a robust and mutually influential connection. The findings underscore a compelling correlation between the augmentation of built-up regions, the ensuing shifts in land use, and the mobility network's expansion in terms of length and area.
- Conversely, the analysis highlights a notable pattern: the expansion of Mazandaran's built-up area directly corresponds with the spread of sprawl and, consequently, the escalation of land consumption. In essence, concurrently, as the mobility network expands, encompassing both increased length and area, a clear and interconnected relationship is established as sprawl intensifies with its associated environmental repercussions. This intricate interplay implies that the Mazandaran polycentric region's mobility system potentially impacts the province's environmental realm.

The conclusions drawn from this analysis suggest that the province's environmental sustainability may come under pressure and exhibit imbalances. The expansion of the mobility network, while essential for connectivity and accessibility, might contribute to the exacerbation of sprawl and its associated negative environmental outcomes. Consequently, a delicate equilibrium must be sought to ensure that the benefits of mobility enhancement are balanced with sustainable land use practices and environmental conservation within the Mazandaran polycentric region.

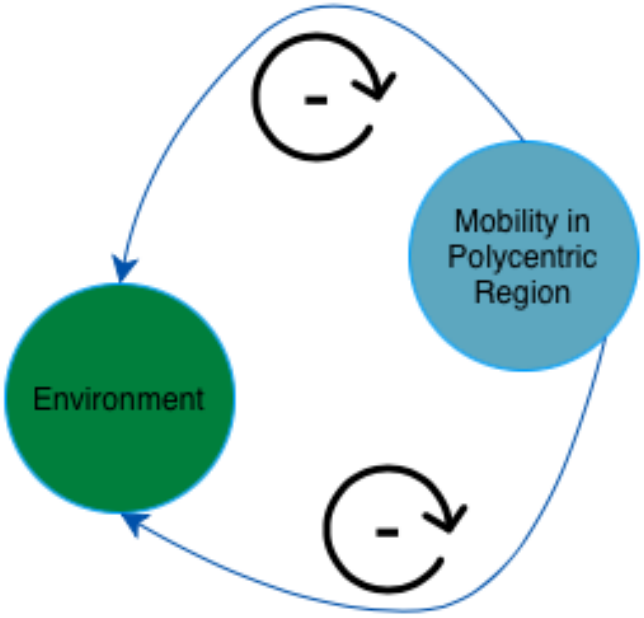


Figure 36 Mobility impact on the environment in the Mazandaran polycentric region

Furthermore, the intertwining dynamics of unregulated urban development, random expansion of mobility networks, and the persistent sprawl phenomenon set the stage for a complex interplay that can be rightly described by the German term "Teufelskreislauf," meaning a "vicious circle." This sophisticated cycle of interactions

unveils both virtuous and unfavorable feedback loops, creating a self-perpetuating system.

A cascade of interconnected effects unfolds within this intricate loop, each exacerbating the others. The uncontrolled urban development and the uncoordinated growth of mobility networks fuel the sprawl expansion, intensifying land consumption and contributing to the cycle's momentum. As land becomes increasingly valuable due to these factors, it triggers a shift in land utilization patterns and massive land use change from valuable ecological lands like forests. These green areas serve the ecosystem and agricultural lands for residential land use (mostly areas with low development quality). This shift, in turn, fosters the establishment of new communities driven by the demand for available land, thus reinforcing the cycle.

However, this self-perpetuating loop does not solely yield positive outcomes. Instead, it brings about a host of unfavorable consequences. The proliferation of sprawl and land consumption leads to more road expansion and consequently congestion, decreased availability of transportation services, and countless related challenges. The repercussions of these dynamics are far-reaching, affecting urban planning, transportation efficiency, environmental sustainability, and the overall quality of life.

The essence of this intricate loop is vividly portrayed in Figure 37, which graphically illustrates the cyclical nature of these interrelated phenomena.

It also visually represents how the interactions between urban development, mobility networks, sprawl, and land utilization contribute to a self-sustaining feedback loop with multifaceted and often unintended ramifications.

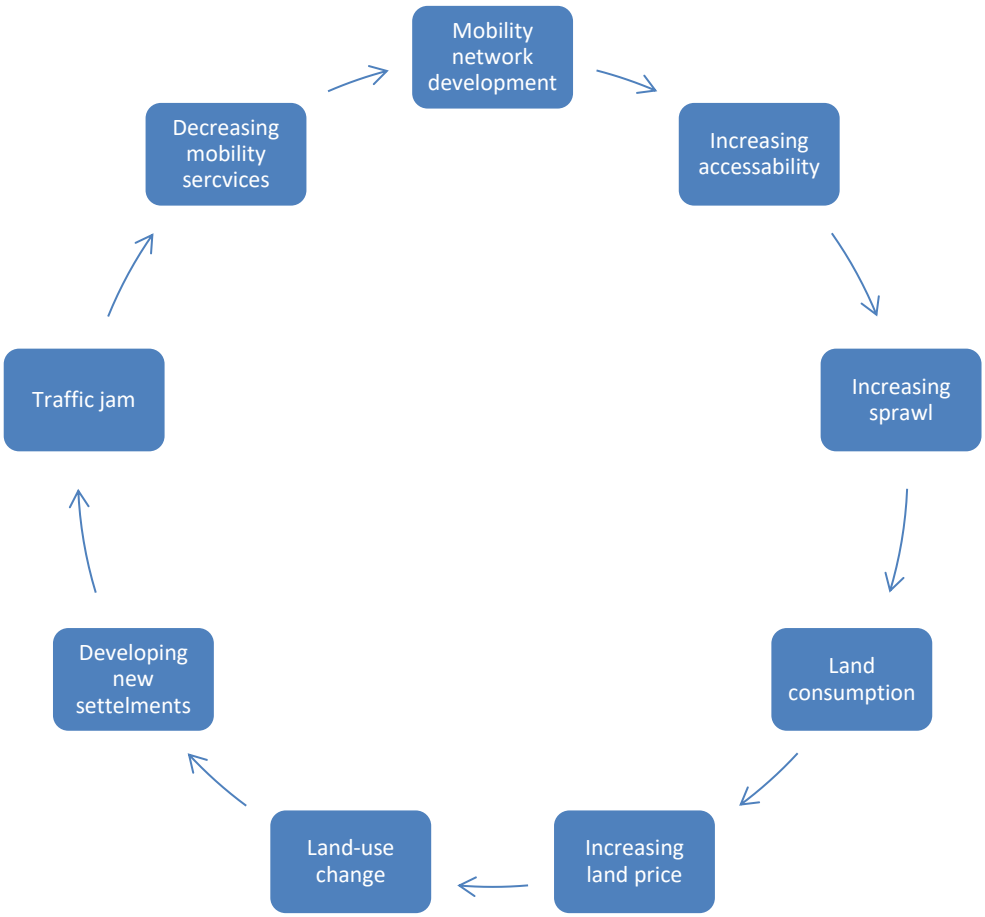


Figure 37 Virtuous and vicious circle of mobility network development and environmental consequences

6.4 Mobility and socio-economic aspects of sustainable development

Drawing upon the conceptual models elucidated in preceding chapters concerning the configuration of central nuclei and the expansion of peripheral hubs within polycentric domains, the outcomes unveiled by this investigation underscore the conformity of Mazandaran to the overarching pattern.

- The visible trend of heightened urban migration to the province's cities has gained prominence alongside the evolution of mobility networks. The concurrent augmentation of employment opportunities within these urban centers further amplifies this trend. Evidentiary support for these assertions is derived from the meticulous statistical analysis of the variables encompassing mobility network development and the growth of Mazandaran's urban population from 2000 to 2020.

- Table 17 (see page 210) concisely encapsulates the results deriving from the Pearson correlation test conducted on the variables of primary mobility network development and population growth within Mazandaran. Across discrete five-year intervals from 2000 to 2020, these analyses convincingly substantiate the intricate interdependence of these variables, elucidating their reciprocal and mutually influential nature. These findings, in turn, provide robust validation for the conceptual paradigms delineating central and peripheral expansion within polycentric landscapes. Moreover, they provide tangible empirical evidence of Mazandaran's alignment with these overarching models.

- However, a distinct narrative emerges when examining the secondary mobility network, notably, a need for more association between the growth of the secondary mobility network and urban population from 2000 to 2010. A meticulous statistical computation based on satellite imagery underscores that secondary transportation networks did not undergo substantial expansion within

those years. Consequently, this outcome points to the absence of significant urban sprawl in the province's minor and major urban centers. Interestingly, this period also witnessed stable urban population growth within Mazandaran.

- Between 2010 and 2020, a transformation in the urban secondary mobility network became evident. The application of the Pearson correlation test reveals a moderate yet discernible association between the development of the secondary mobility network and factors about urban population. This compelling linkage underscores how expanding the secondary mobility network substantially contributes to the growth of Mazandaran's urban population.

- The analysis of Pearson coefficients offers further insights into the interplay between the primary mobility network and employment from 2000 to 2020. Notably, a comparable set of results emerges within the same timeframe when considering Mazandaran's secondary mobility network and its correlation with employment indicators. Additionally, the interpretation of Pearson correlation test outcomes corroborates a robust connection between the expansion of the primary mobility network and the concurrent rise in urban population.

This relationship, characterized by its considerable strength, aligns harmoniously with the similarly effective relationship demonstrated through the Pearson correlation test between the expansions of primary and secondary mobility networks and the concurrent increase in employment within the province. Thus, these findings substantiate the hypothesis that the mobility system significantly strengthens the regional social situation and economy.

The expansion of the mobility network undeniably contributes to the improvement of employment conditions in the province. However, it is important to emphasize that uncontrolled urban population growth, if not accompanied by a concerted focus on essential requirements and the concurrent development of necessary infrastructure, does not necessarily accurately predict the present and future socioeconomic status. The intricate interplay between mobility network expansion and the social component is multifaceted, encompassing both beneficial and adverse aspects. This intricate relationship is aptly illustrated in Figure 38.

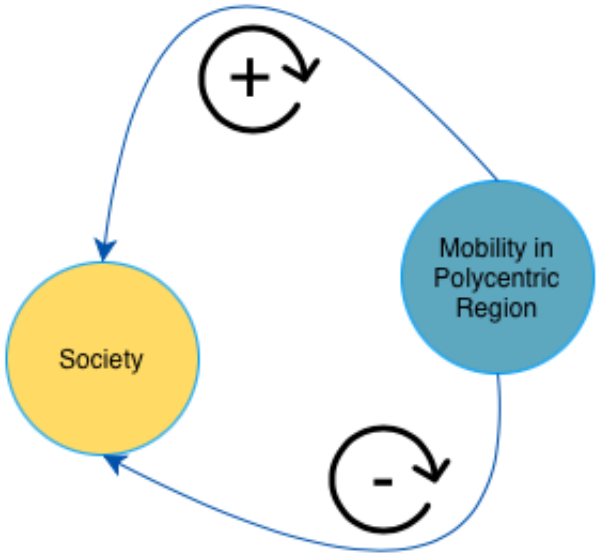


Figure 38 Impact of the mobility system of the polycentric region on the social factors

As such, it becomes imperative for authorities to adopt a proactive approach to addressing these dynamics. Striking a delicate balance between urban development and the expansion of mobility networks while ensuring the provision of essential amenities and infrastructure is key to steering the province towards a sustainable and prosperous future. The interdependence of these factors necessitates strategic planning, effective policies, and comprehensive measures that prioritize economic growth and the well-being and quality of life of the region's inhabitants.

6.5 Mobility and Economic aspects of Sustainable development

Exploring the intricate relationship between the primary and secondary mobility network and their interplay with economic indicators, namely incoming and outgoing parcels, and the displacement of commodities within Mazandaran province during the years 2000-2020 yields enlightening insights.

The convergence of the primary and secondary mobility networks with the ebb and flow of incoming and outgoing parcels is a critical facet of urban economies. The intricate nexus between mobility and its associated facets invariably emerges as a pivotal driver within urban systems, offering a lens through which to comprehend the economic landscape of the research area.

However, the complex demand for mobility, which results from numerous economic and social activities, manifests in numerous ways. The expansion of production, while influential, does not uniformly heighten demand across all transportation modes. Instead, the mode of transit for goods hinges upon intricate attributes encompassing quality, quantity, weight, and economic worth. Given the nature of this research and robust economic data aligned with transportation categories, harnessed from indices chronicling the flow of incoming and outgoing parcels and commodity-displaced traffic within the province, this study navigates the intricate dance of mobility and its far-reaching economic implications.

Notably, the empirical underpinning of this study is accentuated by the outcomes of its statistical analysis, elegantly outlined in table 15 (see page 209). This analysis paints a compelling picture of a substantial correlation between the flux of incoming and outgoing parcel items and Mazandaran's primary mobility network.

- This compelling linkage underscores the province's primary mobility network's pivotal role in seamlessly orchestrating the movement of goods and services.

Remarkably, the expansion of this network over the past two decades has not only streamlined but significantly amplified the influx and efflux of incoming and outgoing parcel products within the province, spanning both local and trans-local deliveries. This economic dynamism has contributed to the province's economic spirit.

- Turning the look to 2000–2010, statistics analysis paints a different narrative, revealing an absence of tangible correlation between the flow of incoming and outgoing parcels and the province's secondary transportation network. This intriguing phenomenon can be attributed to the distinctive nature of Mazandaran's secondary mobility network, primarily serving as an intraprovince intercity line. In this period, the landscape of incoming and outgoing parcels predominantly comprised administrative communication or limited mail among Mazandaran's cities. Consequently, the physical expansion of the secondary mobility network remained relatively subdued.

- However, the record has evolved remarkably from 2010 to 2020. During this phase, a pronounced and mutually significant link emerges between the secondary mobility network and the flows of incoming and outgoing parcels. This convergence can be attributed to many factors, including the growth in urban sprawl.

- The phenomenon of urban sprawl, coupled with the escalating population growth within smaller settlements and their subsequent transformation into urban centers proximate to the primary and pivotal nodes of the province's polycentric network, is a pivotal catalyst for an augmented demand for enhanced mobility solutions. As these once-peripheral settlements evolve into vibrant urban nuclei closely intertwined with the heart of the province's functional landscape, robust and efficient mobility infrastructure becomes essential. The intricate interplay between these elements generates a complex tapestry of urban dynamics, where the burgeoning population and the evolving spatial

configuration work in pairs to amplify the call for advanced mobility systems. This complicated dance between urbanization and mobility encapsulates the essence of contemporary urban development, forging pathways for economic growth, social integration, and sustainable progress. In parallel, modern economic dynamics, including the surge of online storefronts, digital commerce for local products and services, and providing services to neighboring cities and within the province via a secondary mobility network, all contribute to the fluid circulation of goods and services. However, a pivotal enabler in this thriving ecosystem of incoming and outgoing parcels and economic prosperity is unequivocally the maturation of the secondary mobility Network.

The assessment of commodity displacement within Mazandaran province, facilitated by its primary and secondary mobility networks, constitutes another pivotal economic indicator interwoven with the fabric of the mobility network and the province's pursuit of sustainable development.

- Delving into the statistics presented in table 16 (see page 210), focused on the span from 2000 to 2010, a substantial correlation emerges between these metrics: Commodity displacement and mobility network development. Within this timeframe, the primary roads embedded in the mobility network assumed a central role in directing the intricate flow of goods and commodities, services, and passengers coursing through Mazandaran province. Without alternative road networks or prominent transportation modes, the primary mobility network emerged as the essential line underpinning the province's mobility landscape. Any strides undertaken to support the development of this network during the study period inevitably translated into an uptick in the movement of goods, services, and commodity-displaced flows within the province's borders.
- However, the period spanning 2010 to 2020 paints a different picture. Notably, there were no significant associations between the development of the primary mobility network and commodity displacement during this period. A parallel

scenario echoes within secondary mobility development and freight displacement from 2000 to 2020, indicating a lack of substantial correlation.

- Analyzing these statistical findings reveals an intriguing shift in Mazandaran's production system—a region where horticultural and agricultural products predominate. Over time, Mazandaran's land utilization has changed notably, shifting from its agricultural roots to accommodate burgeoning residential domains and establishing new population centers—trends aptly substantiated by sprawl data. Unfortunately, this change has sharply declined productivity, affecting cargo handling within the province.
- Furthermore, the years spanning 2000 to 2010 shed light on a period where the province's primary mobility network played a pivotal role, forming the cornerstone of its major transportation and mobility endeavors. However, after this period, a transformation occurred. The advent of the secondary network's development, coupled with the escalating influence of urban sprawl and its resultant impact on commodity displacement, has necessitated a more balanced distribution of mobility loads, spanning both the primary and secondary mobility networks. This transition underscores the dynamic interplay between mobility infrastructure, urban expansion, and the multifaceted dynamics of economic activity within Mazandaran province.
- By delving into the intricate interplay between Mazandaran's primary and secondary mobility networks and their correlation with economic indicators such as incoming and outgoing parcels and commodity displacement from 2000 to 2020, a significant understanding unfolds. Despite variations in the relationship and reciprocal influences, a consistent conclusion arises: the expansion of mobility networks generally yields a positive effect on the regional economy and, consequently, on the trajectory of sustainable development.

Nevertheless, concerning the impact of transportation infrastructure development on economic growth, extensive research has been conducted in recent decades, resulting in a wide range of findings. In this context, scholars such as Heintz et al. (Heintz et al.,

2009) assert that the development of infrastructure, especially transportation infrastructure, is widely acknowledged as a fundamental requirement for fostering economic growth.

Furthermore, Zhang & Cheng, (Zhang & Cheng, 2023) suggests that transportation infrastructure has a lasting and positive influence on economic development. Scholars like Meersman & Nazemzadeh(Meersman & Nazemzadeh, 2017) argue that it can significantly enhance a country's economic performance.

Given this background, the results of this study regarding the relationship between Mazandaran's mobility network and economic and social indicators reaffirm the notion that mobility and transportation infrastructure, both directly and indirectly, contribute to economic development.

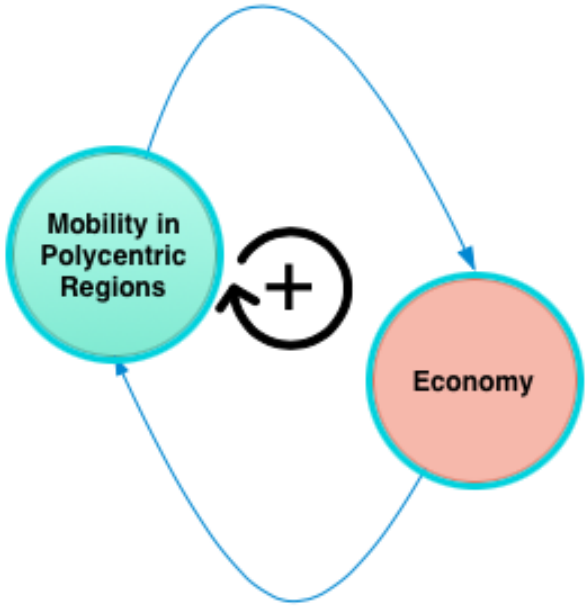


Figure 39 Mobility impact on the environment in Mazandaran polycentric region

Based on this study's comprehensive literature review and empirical analysis, the intricate interplay between the mobility system and sustainable development processes within the Mazandaran polycentric city-region manifests a complex web of positive and negative consequences.

In the social and economic dimensions, the development and enhancement of the mobility network foster a facilitative environment within the province. This is achieved by creating a favorable economic landscape with increased employment opportunities, trade facilitation, and convenient commuting for the province's residents.

However, when delving into the environmental dimension, it becomes evident that any advancements in the province's mobility infrastructure catalyze the acceleration of urban sprawl. This, in turn, initiates irregular and unregulated physical development throughout Mazandaran. This process sets in motion a dynamic cycle, oscillating between virtuous and vicious states. This intricate interrelationship is particularly exacerbated within the polycentric centers of Mazandaran regions as urban centers and settlements draw closer.

To articulate this more explicitly, the unstructured and random development resulting from mobility network development exerts immediate and tangible adverse effects on the environment. This is evident in the consumption of valuable land resources to accommodate the development of motorized mobility infrastructure, leading to short-term environmental degradation. Over the long term, this trajectory fuels further urban settlement expansion, quickening the pace of urban sprawl and the expansion of built-up areas. Consequently, this translates to increased land utilization for residential purposes and places additional strain on the environment due to the demands associated with urban lifestyles.

The accompanying figure illustrates the overarching impacts exerted by the mobility system within Mazandaran's polycentric region across various dimensions of sustainable development.

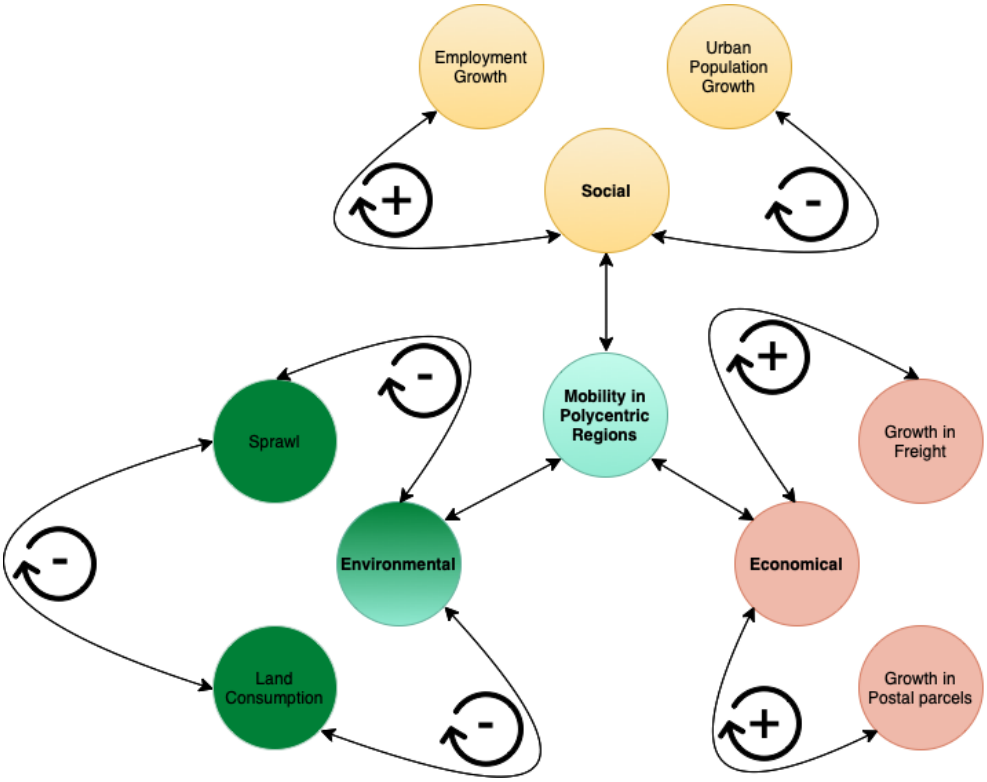


Figure 40 Impact of the mobility system of Mazandaran on different aspects of the sustainable development of the region

In summary, the findings of this study shed light on the impact of the mobility system within the Mazandaran polycentric region on sustainable development and urban expansion. The key conclusions can be summarized as follows:

1. **Environmental impact**: The mobility system has a notably adverse effect on the province's environmental conditions. It contributes to urban sprawl and irregular urban development, negatively affecting the environment by consuming valuable land resources.

2. **Polycentric characteristics**: The Mazandaran mobility system exhibits characteristics consistent with a polycentric mobility framework. However,

there is a lack of integration in various planning, implementation, and operation phases, leading to system inefficiencies.

3. **Dominance of road traffic**: Mazandaran's mobility system heavily relies on road traffic and private vehicles. Efficient public transport in urban centers and settlements is absent.

4. **Lack of regional integration**: There is a deficiency in integrating planning and operating the mobility system at the regional level.

5. **Sprawl dynamics**: Urban sprawl in Mazandaran is primarily propelled by the province's polycentric structure, characterized by the proximity of cities and settlements. This sprawl is further encouraged and facilitated by developing the province's mobility network and related infrastructure.

6. **Weak regulatory instruments**: Inadequate legal and implementation instruments for controlling urban development and securing boundaries contribute to continuous urban expansion in the province.

7. **Fragmented decision-making**: Despite the province's polycentric structure, decision-making and planning processes for counties and cities lack cohesion. This fragmentation in planning and development authorities creates instability in infrastructure development, including mobility and settlement development, and hinders the province's sustainable development efforts.

7 Discussion and Recommendations

7.1 Introduction

As described in earlier chapters, the key challenges facing the province in its pursuit of sustainable development are the interrelated systems of mobility and human settlement and development. Importantly, statistical analysis confirms a mutual relationship between these two systems. In essence, development in the province's human settlements leads to corresponding development in the mobility system, and conversely, developments in the mobility system influence the state of human settlements. Nevertheless, it is crucial to recognize that these interconnected processes significantly negatively influenced the environmental conditions within Mazandaran province.

Certainly, human settlement development in Mazandaran has unfolded unplanned, manifested notably through urban sprawl and the erosion of urban green boundaries. These processes have also triggered substantial changes in land use, resulting in the significant loss of ecological lands within the province.

Also, the effects of the mentioned challenges on sustainable development can be discussed in detail, and suggestions were also considered to improve these processes by considering the successful experiences of the world that were discussed in the previous chapters of the research.

However, within the research framework, the author considered Mazandaran's primary challenges in the context of sustainable development can be categorized into the following areas:

- **Urban and regional management and planning.**
- **Transportation system planning and management.**

7.2 Urban and regional management and planning

Within urban and regional management challenges, the polycentric Region of Mazandaran grapples with many pressing issues. These challenges primarily arise from the lack of a well-defined policy and decision-making framework tailored to the intricacies of a polycentric region. As we delve deeper into the subsequent stages, Mazandaran province confronts many problems. These include the absence of adequate tools to regulate urban development, the need to curb urban sprawl, and preserving the natural green boundaries that envelop its cities. The convergence of these factors contributes to environmental degradation and an imbalanced development pattern. This intricate web of challenges constitutes a formidable barrier to the province's progression towards sustainable development.

In the forthcoming sections, it will be discussed some of the most paramount challenges that the Mazandaran province faces in this field.

- **Lacking proper governing and decision-making system for urban and regional planning:** As highlighted in the research by Mahmoudi-Pati et al. (Mahmoudi-Pati & Abaszade-Soorami, 2019), Asadi et al. (Asadi & Barakpoor, 2021; Asadi & Zebardast, 2022), Barakpoor et al. (Barakpoor & Asadi, 2022), and Latifi (latifi, 2004) the urban and regional management and planning system in Iran operates under a framework of centralization. This centralization has posed significant challenges in governing urban areas across the country. Moreover, phenomena like urban sprawl, extensive land use changes, and the resulting adverse environmental impacts can be attributed directly and indirectly to this centralized system.
- **Lack of recognition of polycentric structure in management and planning system:** Haqjou's (Haqjou, 2018) perspective also underscores that Mazandaran faces a significant challenge due to the neglect of its polycentric spatial structure by the national and local administrative system. In the case of Mazandaran, the national administrative system treats it similarly to other

provinces and metropolitan cities in Iran. Consequently, the same planning and decision-making processes are applied to the region without considering its distinct environmental and spatial characteristics. This challenge exacerbates the issues that Mazandaran province faces in regional management and planning.

- **Land-use changes and desecration of cities and valuable ecological areas:** Mazandaran polycentric region is suffering massive land-use changes of the ecological valuable lands, including green boundaries of the urban centers, forests, agricultural land to the built-up area, and urban sprawl is continuously degrading the landscape of the region. Further, the pressure of demanding critical infrastructure regarding municipal waste management, directly derived from developing urban centers and increasing urban lifestyle within the Mazandaran polycentric region, negatively impacts the province's natural landscape.

Last but not least, the different desires and competition of the urban centers and cities within Mazandaran polycentric regions exacerbated these challenges and, in the short term and long term, negatively impacted the province's environmental and spatial landscape.

However, as evidenced, an integrated and comprehensive manner of planning and management by national and local authorities is required to deal with challenges. However, dealing with challenges is not possible with the current sectoral and fragmented policy decision-making and administrative system of the country.

7.3 Transportation system planning and management

In the polycentric city-region of Mazandaran, Iran, roads and motorized vehicles persist as the primary means of transportation. As highlighted in preceding chapters, the current transportation paradigm grapples with many challenges beyond environmental considerations. These challenges also exert significant influence on the spatial development of the province, several of which are discussed below:

- **Dependence excessively on road infrastructure**: The province's exclusive dependence on road networks as the primary mode of transportation constitutes a pivotal and foundational concern. Relying heavily on road transport will lead to several adverse consequences, including the proliferation of motorized land use patterns, limited transportation alternatives, and increased transportation-related costs. These costs can manifest in various ways, encompassing higher vehicle expenses, reduced travel options, elevated road and parking facility costs, exacerbated traffic congestion, increased accident-related damages, and a range of detrimental environmental impacts like air pollution. Moreover, this reliance on road networks triggers direct and indirect modifications in land use patterns, resulting in a far-reaching network of environmental hazards. These multifaceted changes demand immediate attention and resolution to ensure the long-term sustainability and well-being of the province.

- **Inadequate intra-city and regional rail connectivity:** Lack of intra-city and regional rail networks: one of the significant shortfalls in the province's transportation infrastructure is the absence of intra-city rail networks as part of its public transit system. Simultaneously, given the relatively short distances between urban centers and the frequent back-and-forth travel typical of polycentric regions, there is a pressing need for a comprehensive regional public transportation system prominently featuring rail networks. Such systems possess the potential to alleviate traffic congestion, promote sustainable and

efficient commuting options, reduce carbon emissions, and enhance overall safety in travel and transportation. However, on the urban front, the cities within Mazandaran province currently lack a rail network to facilitate intra-city transportation. On a regional scale, the existing rail infrastructure in the eastern part of the province is minimal, with its primary focus primarily on cargo transportation, resulting in limited performance for passenger transport.

- Consequently, it becomes imperative to prioritize the development of the regional rail network, not only to bridge the divide between the western and eastern parts of the province but also to establish vital connections with key urban centers. In essence, the province's development plans must encompass the expansion and enhancement of its intra-city and regional rail networks as fundamental components. This endeavor has the potential to not only mitigate the challenges associated with traffic but also to bolster the province's standing in sustainable and secure transportation, thereby fostering its overall progress and prosperity.

- **Inadequate public transportation:** Today, one of the key benchmarks for measuring a city's progress is its development in Mobility (Wong et al., 2020). Sustainable urban mobility entails the efficient flow of vehicles, people, and goods while ensuring the well-being of residents and the preservation of the environment, all at minimal cost and effort. In urban areas, the bedrock of such a mobility system typically lies in developing a robust public transportation network. Simultaneously, it is imperative to emphasize the significance of public transportation and the establishment of a comprehensive mobility system within cities, aligning with each city's unique social, environmental, and economic capabilities. However, it is worth noting that the public transportation systems in small and medium-sized cities across Iran are not uniformly efficient. Except for major metropolitan cities like Isfahan, Mashhad, Shiraz, Tehran, and Tabriz, which have implemented bus and partial

subway systems, the prevailing concept of public transport in Iran primarily relies on taxis, with buses playing a secondary role.

The cities within Mazandaran province are no exception to this pattern. Public transportation primarily hinges on taxis in the province's primary population centers, including Sari, Amol, Babol, Behshahr, and Qaimshahr, which collectively constitute the core of the Mazandaran Polycentric City-Region.

Regrettably, this underdeveloped public transportation framework, heavily dependent on motorized vehicles, has not only failed to progress in recent years but has also witnessed a decline in efficiency as the cities of Mazandaran have experienced substantial physical and demographic development. Consequently, the current taxi-centric public transportation system has become increasingly inadequate, leaving the cities of Mazandaran without a minimally functional public transportation system.

To address the unique Polycentric structure of Mazandaran Province, a comprehensive public transportation system for this province must operate at both the local and regional levels. This means providing mobility services within urban areas and extending these services to neighboring settlements based on socioeconomic and environmental considerations.

From both economic and social perspectives, achieving equitable transportation access and cost allocation is crucial. From an environmental standpoint, such a system can be characterized by optimal fuel consumption or incorporating renewable energy sources.

- **Integration of mobility plans:** The integrated transportation approach is a sustainable transportation strategy proposed to address disparities and inconsistencies in the management of transportation services. Indeed,

Integrated mobility embodies a transportation system characterized by a well-defined movement hierarchy that considers access carefully. Upholding this movement hierarchy entails that a city should offer a spectrum of transportation options, such as taxis, buses, metros, and rail systems, proportionate to its population and size. The integrated transportation approach is a sustainable transportation strategy proposed to address disparities and inconsistencies in the management of transportation services.

Urban mobility planning encompasses various aspects, including the strategic design of integrated public transport routes. This involves deliberations about the master transportation plan, terminal locations, feeder lines, and accessibility. These considerations should ideally be embedded within the framework of development plans.

Regrettably, this crucial aspect has been overlooked in the planning documents of Mazandaran province, whether at the regional or local level. This omission constitutes yet another contributing factor to the imbalance and unsustainability of the mobility network within Mazandaran province.

Another significant hurdle in achieving an integrated mobility system is the lack of attention devoted to multimodal transport, which seamlessly interconnects all available transportation options within a region, promoting sustainable mobility across urban and regional networks.

Consequently, due to its polycentric structure, Mazandaran province demands a mobility network that operates cohesively and efficiently and is multifaceted. Unfortunately, this essential facet has been neglected in major development plans for the Mazandaran region and even in its cities' more localized development plans. This oversight underscores the need for a strategic

reevaluation of transportation planning to ensure a comprehensive and sustainable mobility framework in the province.

- **Lacking integration of urban land use and transportation activities:** Greater integration of urban land use and transportation functions exacerbates urban sprawl, resulting in inefficient land utilization and increasing transportation issues. A comprehensive approach combining land use and transportation planning is required to address this issue. In other words, integrated planning of urban land use and transportation, often known as transportation and land use coordination or urban planning, constitutes a comprehensive strategy. Its objective is to harmonize and synchronize the evolution and administration of a city or region's transportation infrastructure with its land utilization arrangements. The overarching aim is to cultivate urban environments that are more operationally efficient, sustainable, and conducive to a higher quality of life.

  Furthermore, integrating urban and regional land use planning with mobility planning establishes a synergistic connection between mobility infrastructure and land use configurations. This synergy is a preventive measure against undesirable land-use alterations and the sprawl phenomenon that may arise from expanding transportation systems, such as roads and accessibility enhancements.

  However, such an important matter will be highlighted more in polycentric regions with proximity between urban and settlement centers, particularly in developing countries that do not have an efficient instrument to control sprawl and uncontrolled development.

  The remote sensing analysis discussed in previous sections illustrates that the Mazandaran polycentric region experiences extensive land-use

transformations. These land-use changes are closely intertwined with the advancement of the mobility network, and the relationship between the two is reciprocal. Given this intricate dynamic, the imperative of integrating the development of the mobility network with urban and regional development plans becomes even more pronounced. Such integration can mitigate the sprawl phenomenon and, conceivably, decelerate the pace of land use change in Mazandaran.

7.4 Guideline for dealing with Polycentric City-Region

However, the author believes benefiting a successful world experience of dealing with a polycentric area can be useful to consider for dealing with Mazandaran challenges concerning planning, management, and urban developing control within its polycentric spatial arrangement, which left a negative impact on its environmental situation and hindered sustainable development process.

In exploring successful global experiences in handling polycentric regions, the preceding chapters scrutinized three cases: the Ruhr region and Stuttgart region in Germany and the Randstad region in the Netherlands. Despite their geographical and administrative differences, these regions encountered similar challenges inherent to polycentric regions, irrespective of their location, as follows:

1. Integrated planning and management system
2. Preserving valuable ecological land
3. Preventing massive land-use change
4. Controlling urban development
5. Competition between urban centers

6. Public transportation

In the case of the Stuttgart and Ruhr polycentric regions in Germany, the German federal government, in collaboration with state authorities (Nordrhein-Westfalen and Baden-Württemberg), established specific organizations to address these regions' unique challenges. These organizations, namely the Regional Association of Ruhr (RVR) and the Stuttgart Region Association (VRS) were granted legal instruments and responsibilities for urban and regional planning and management. They were tasked with developing green areas, preserving valuable ecological lands within the region, and safeguarding urban boundaries from unplanned development by creating and maintaining green belts.

In the Randstad Polycentric Region in the Netherlands, the Dutch government mandated cooperation among cities in the Randstad region at various stages of urban and regional planning. Simultaneously, the government sought to control competition between urban centers, a common occurrence in Polycentric Regions that can lead to uncontrolled urban development.

The Green Heart plans were introduced to address uncontrolled urban development, the demarcation between urban centers, and the preservation of ecologically valuable land. These plans focused on maintaining green belts, green areas or open spaces between urban centers.

Considering these successful approaches in Germany and the Netherlands, which have different administrative and planning systems, the following recommendations can be applied in Iran and other polycentric regions:

1. **Voluntary municipal cooperation:** Drawing from the experiences of the Ruhr polycentric region over several years in navigating the competitive dynamics among cities in close proximity within a polycentric context, it becomes evident that one of the pivotal strategies for addressing the complexity of competition and diverse interests in such regions is fostering

collaboration among municipalities. This collaborative effort can effectively address challenges that impact all the nearby cities or delineate shared projects that operate at the scale of the involved municipalities.

Regional or central government entities can initially initiate and define this cooperative endeavor. Subsequently, it can be sustained through the involvement of local authorities, exemplified by the work of Robert Schmidt, a prominent municipal official from the city of Essen during the early 1900s. Schmidt's efforts underscore the value of partnerships and cooperation among local governments, setting the initial groundwork for establishing the regional association that serves as the overarching body overseeing the management and planning of the Ruhr polycentric region today. Taking such a step further emphasizes the significance of establishing well-defined legal mandates and allocating specific responsibilities to "regional planning organizations." These organizations are pivotal in uniting diverse stakeholders within a single overarching entity.

2. **Establishment of a unified authority for comprehensive planning and management:** In pursuing integrated urban and regional planning within a polycentric region and dealing with the problem of fragmented decision-making, the establishment of a dedicated institution is imperative. Depending on the political and administrative context of the target country or region, this institution can take various forms, including an organizational body or a legal entity under the purview of the central or federal government. This entity must possess the requisite authority to effectively address and resolve potential conflicts of interest among the urban centers within the polycentric region. Furthermore, it should shoulder responsibilities encompassing regional planning facets, such as the regional open space framework, environmental planning, transportation infrastructure, public transport coordination, waste management, economic development, and tourism promotion. This underscores the extensive and multifaceted role that regional planning

organizations can assume in overseeing and harmonizing activities within a polycentric region.

3. **Controlling urban development:** Given the short distances between urban and human centers in polycentric regions, there is always a risk of expanding built-up areas near or beyond their boundaries. This development leads to land-use changes and demarcation between regional centers, resulting in the loss of valuable ecological lands. Therefore, strict control over urban development within the established boundaries is essential in a polycentric region. Administrative instruments should be established at the highest level of government with adequate authority to restrict any development between centers and actively work towards expanding green areas within the Polycentric region and the urban centers themselves.

4. **Protecting urban boundaries by establishing and preserving regional green belts:** Regional green belts protect open spaces from unregulated land consumption and development, particularly in metropolitan areas. These green belts offer a range of benefits, including ecological functions, recreational spaces, and protection for agricultural and forested areas. They also contribute to improved air quality, provide recreational opportunities, and safeguard water-producing regions. Moreover, green belts significantly influence urban development by acting as control zones that guide the growth of urban areas, ensuring the expansion of central cities and suburbs while conserving open space.

5. **Integrated Planning and Management:** Comprehensive and integrated management and planning processes are vital for effectively addressing the complexities of a polycentric region. The experience of the discussed regions in Germany and the Netherlands illustrates the necessity for a unified approach to managing diverse features and challenges within polycentric regions. Innovative governance structures, like the German experiences for the

polycentric regions, emphasize the importance of flexible and adaptive systems in dealing with the dynamic of polycentric regions and multi-tier planning systems like the case of Stuttgart. Such flexibility is essential to meet a polycentric region's multifaceted demands effectively.

6. **Recognizing polycentric regions as unique regions with particular spatial characteristics:** Polycentric regions demand a specialized planning and management approach due to their unique characteristics and challenges. These challenges include the proximity of centers, the potential for rapid development and sprawl, pendulum commuting patterns between centers, cultural competition, developmental dynamics among centers, etc. To address these intricacies effectively, decision-makers and planners must view polycentric regions as distinct entities. They should refrain from applying one-size-fits-all policies similar to those used in other regions of the country.

7. **Establishing cooperative alliances for integrated public transport:** In Germany, addressing public transport within a vast and diverse region involves using cooperative alliances for integrated public transport services, known as "Verkehrsverbund." This innovative system fosters collaboration among stakeholders and local administrations to establish an integrated transport network, simplifying public transport accessibility. Verkehrsverbund offers diverse collaboration models, ranging from subarea coordination to comprehensive organizations responsible for managing fares, networks, and timetables. The primary goal of this alliance is to seamlessly integrate public transportation systems, eliminate competition, and enhance coordination across different modes of transport.

   Moreover, establishing such a transportation alliance can smooth the transition to regionalization, which involves a redistribution of authority from transportation companies to local authorities. Managing the financial aspects and relationships between municipalities, Verkehrsverbund, and transport

companies can be complex, necessitating tailored approaches considering each country and region's administrative and local nuances.

"Verkehrsverbund" has evolved into a crucial element of Germany's transportation system, leading to the expansion of services, a rise in passenger numbers, and a stable or growing trend in public transport usage. This successful German model, which balances the varied interests of stakeholders and effectively addresses the mobility challenges in regions characterized by proximity between centers and intense competition, has also found application in some areas of other countries, including Austria, Switzerland, and the Netherlands. Its adaptability and flexibility make it well-suited for both polycentric and monocentric regions, underscoring its capacity to meet the diverse transportation needs of different regions.

8. **Decentralization and deconcentration**: Experiences drawn from the Randstad polycentric region in the Netherlands demonstrate that prioritizing decentralization and deconcentration, focusing on harnessing local and regional capabilities, can effectively rebalance economic development, alleviate congestion, and strengthen regional competitiveness. In this sense, to address urban challenges and foster economic growth across various zones within a polycentric region, decentralizing economic activities and consolidating autonomous communities have emerged as strategies to create a more secure, prosperous, and equitable society.

9. **Urban Networks and interconnectivity:** The notion of a networked city, as observed in the Netherlands in response to the challenges posed by polycentric regions' cities, is prominently featured in the development of the Randstad region. This approach seeks to strengthen urban networks through new construction and infrastructure initiatives. Integrating various cities into a cohesive network can significantly enhance their collective competitiveness. Drawing from the insights mentioned earlier, it becomes evident that

developing urban networks and enhancing interconnectivity between cities can catalyze economic growth and collaboration.

In a general context, the planning experiences of Germany and the Netherlands underscore the paramount importance of prioritizing regional and local capacities within the planning process. A departure from a top-down perspective, eschewing singular tools and structures in favor of decentralization, bears significant potential for yielding favorable outcomes in both urban and regional planning endeavors.

The inception of cooperative relationships among cities within a polycentric region, focusing on shared motivations, constitutes the initial stride toward realizing planning and sustainable development objectives. This pivotal undertaking necessitates an incremental approach from its inception.

To establish a framework that accentuates the collective challenges confronting a polycentric region, the central government must institute a high-authority entity at the regional level, accompanied by the provision of requisite legal instruments to facilitate intercity collaboration. This entity is equally instrumental in advancing regional planning and management goals, which are integral to achieving sustainable development objectives.

To mitigate competition and interference between regional municipalities, this institution must address three pivotal regional challenges: waste management, environmental stewardship, and public transportation. This can be achieved by acting as a protective umbrella entity and assuming executive responsibilities in the mentioned domains.

In polycentric configurations, urban neighborhoods are well-positioned to manage physical development and combat urban sprawl while concurrently preserving the area's ecological integrity, notably through the utilization of green belt strategies. The historical experiences of the Ruhr region, Stuttgart, and Randstad in the Netherlands underscore this approach's significance.

Establishing a cooperative platform for integrating public transportation management, particularly focusing on rail and multimodal transportation, as evidenced in the European cases of the Ruhr region, Stuttgart, and Randstad, has yielded advantageous outcomes within public transportation. Sustained attention to the seamless integration of public transportation management, planning, and operational aspects is indispensable for long-term development within a polycentric region.

8 Conclusion

8.1 Introduction

Analyzing the mobility system's impacts on sustainable development in developing polycentric regions is inherently challenging due to the unique geographical characteristics, structural complexities, and scarcity of reliable data for comprehensive analysis.

However, this research aims to clarify the nexus between mobility systems and sustainable development in developing polycentric regions. This has been achieved through an in-depth exploration of the intricate interplay between mobility and the fundamental pillars of sustainable development, encompassing environmental, economic, and social dimensions. Furthermore, it entails an examination of the dynamic interactions among these elements within the spatial framework of Polycentric systems in developing nations.

The significant findings and highlights from the preceding chapters are synthesized in this concluding chapter. These encompass but are not limited to, an exploration of the spatial ramifications arising from urban sprawl and expansion in polycentric regions, the identification of challenges and issues inherent to developing polycentric areas, the introduction of a robust research methodology and framework for assessing the sustainability of these regions while factoring in their mobility systems, and the discussion of encountered challenges, research limitations, contributions to the body of knowledge, and potential openings for future research endeavors.

8.2 Research questions

As the global population rises, developed and developing countries face challenges related to human settlements and urban development. Rapid urbanization in developing nations leads to uncontrolled urban sprawl, with major and medium-sized cities expanding into low-density, irregular neighborhoods. This expansion results in diverse land-use patterns, transportation methods, and building structures.

Despite the negative consequences associated with sprawl and urban expansion, it can sometimes lead to forming a special region with special characteristics like polycentric frameworks within cities and regions. However, it is essential to note that the emergence of polycentric city-regions is not solely a consequence of sprawl and urbanization. Developing countries often face challenges related to polycentric city-regions due to the absence of effective urban planning and management systems, complex interrelationships, and the need to develop strategies for effective governance.

For settlement centers within Polycentric regions to pursue economic development, it is imperative to transform the mobility and transportation systems as part of a spatial harmonization strategy. This transformation will result in altered land and resource utilization patterns within the regions, ultimately fostering a sustainable development process. In this regard, this research addresses several interconnected difficulties and assumptions, striving to address them through the following questions and assumptions which in this research tried to deal with.

- **Does the structure of the Polycentric city-region mobility system influence the dimension of natural environment sustainability in the context of the region's sustainable development?** It is pertinent to initially acknowledge that the configuration of the Polycentric city-region mobility system appears to exert a discernible impact on the excessive utilization of natural resources, including ecologically valuable lands. The primary variables under scrutiny in this question encompass the extent of built-up areas and the

magnitude of land utilization attributable to sprawl and urban expansion.

The findings derived from this research endeavor indicate that, due to the inherently polycentric nature of the region, a significant and mutually reinforcing relationship exists between the expansion of built-up areas, alterations in land use patterns (land use change), and the development of the mobility network in terms of its spatial extent and, consequently, the land area it encompasses within the region's urban centers. Within a polycentric spatial framework characterized by the approximate clustering of human settlements and activity hubs, coupled with a pronounced pattern of pendulum travel between these centers, there is a notable surge in travel frequency. Consequently, this heightened travel demand necessitates expanding and enhancing motorized mobility infrastructure, mainly when a rail network and efficient public transportation systems are notably absent—a common scenario in developing nations. This infrastructural development, predominantly focused on road networks, translates into a corresponding increase in the consumption of natural capital by using valuable lands, including public green spaces and protected areas, to develop road networks, effectively exacerbating the demand for further mobility infrastructure expansion, particularly in the absence of a well-established rail network and efficient public transportation systems.

- **Does the mobility system configuration influence sustainable regional development's economic efficiency aspect?** An exploration of mobility and its economic ramifications becomes imperative. Due to the nature of this investigation and the availability of reliable economic data explicitly about transportation, two key datasets have been utilized: firstly, the index of incoming and outgoing parcel item flow within the province's communication networks, encompassing both inbound and outbound postal goods to and from neighboring provinces; and secondly, the volume of commodities displaced via specialized transportation means within the province. Statistical

analyses conducted as part of this study unveil a significant correlation between the flow of incoming and outgoing parcels and the primary mobility network of the province. Remarkably, this correlation holds for the period spanning from 2010 to 2020, illustrating a persistent and reciprocal significance between incoming and outgoing parcel item flows and indicators related to the secondary transportation network.

Additionally, the flow of commodities displaced within Mazandaran province is another vital economic indicator intimately linked to the mobility network's configuration and interplay with the broader networks. The analytical findings support a robust relationship between commodity-displaced flows and the primary mobility networks within the Mazandaran polycentric region.

The underlying assumption associated with this research question posits that "the nature of the polycentric city-region mobility system may render economic linkages inefficient." However, this assumption is not substantiated and is refuted based on the empirical evidence derived from this study. It becomes evident that the polycentric structure of the province, characterized by its spatial proximity to the region's centers, the secondary mobility network, and its recent development—fueled by the surge in online shopping and the resultant increase in incoming and outgoing parcels—has notably facilitated the flow of postal parcels across different scales. Consequently, it can be inferred that the polycentric structural configuration positively influences the region's economic dimension.

- **Is the framework of the Polycentric city-region mobility system affecting the social structure and dimension of Mazandaran's sustainable regional development?** An analysis employing pertinent variables, namely, employment growth and urban population growth, reveals a discernible trend of rural-to-urban migration within the province. This trend becomes increasingly prominent as transportation networks develop and employment

prospects in urban centers improve.

The statistical analysis conducted on the variables of mobility network development and Mazandaran's urban population growth from 2000 to 2020 demonstrates a moderate association between the development of primary and secondary mobility networks and urban population dynamics. Furthermore, the Pearson correlation test corroborates a significant relationship between the expansion of primary and secondary mobility networks and the growth in employment within the province. These findings collectively indicate that the mobility system exerts a positive influence, increasing population and employment and, by extension, fostering the region's economic prosperity.

In light of the hypothesis underpinning the third research query, "The structure of the polycentric city-region mobility system appears to have an impact on all social constructs," it becomes apparent that the polycentric spatial configuration of the province facilitates rural-to-urban migration due to the proximity between urban centers. The sprawl and rapid urban expansion further amplify this migration trend. Consequently, due to the employment opportunities within the service sector and potential industrial activities in cities, there is a concurrent increase in the number of individuals gainfully employed.

However, it is imperative to acknowledge that mass migration from rural areas or smaller cities to major urban centers and employment opportunities constitute a dynamic but potentially unstable phenomenon. In the long run, such trends may impede the region's sustainable growth in both economic and social dimensions.

8.3 Research limitations

The availability and accessibility of information posed significant challenges and limitations throughout this study. Unfortunately, due to structural challenges, the complexity of management institutions, and issues related to statistics in developing countries, up-to-date statistical information for the study was lacking.

A compilation of statistical data in urbanization, transportation, and economic information was undertaken to address this limitation. These statistics were sourced from official statistical data provided by various authorities. Additionally, the author took responsibility for developing and generating a substantial portion of the required statistical information for the research.

Another significant issue affecting this investigation was the global outbreak of coronavirus, which has led to strict travel restrictions and limited in-person visits to research sites. Consequently, the compilation of this dissertation and the ongoing work on it have required a significant amount of time.

8.4 Further Research

The assessment of the built-up area in the Mazandaran polycentric city-region in this study, aimed at investigating land consumption and land cover change, has yielded valuable data regarding the province's extensive land use changes and environmental degradation. Furthermore, this case study of Mazandaran, Iran, opens up numerous avenues for future research on related themes. While the following areas are suggested for further exploration, it is important to note that research should not be limited to these proposals:

- Investigating the sprawl trend in Mazandaran polycentric urban areas.
- Examining sprawl forecasts and present trends in rural areas centered in polycentric regions.
- The formation of an urban conurbation in Mazandaran's polycentric region.

- The need for integration planning and management organizations for polycentric city areas in developing countries.
- Comprehensive studies on changing the structure of mobility network planning and operation in Mazandaran province.
- Studies on the development of intra-city and inter-city rail transport network in Mazandaran province.

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