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# Searching for economic synergy and sustainability in Tehran metropolitan region

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ABSTRACT

Over the past few decades, urban areas have become hubs for economic activity, especially industrial activity, because of economies of scale and agglomeration. Lack of compliance with the environmental regulations and frameworks has led to environmental unsustainability in these regions over time, and Tehran Metropolitan Region (TMR) as one of the concentrations of industrial activities is encountering environmental issues these days. This study sought to determine the degree of environmental unsustainability as well as these locations' potential for economic synergy. In this study, economic synergy potentials and sustainability were implemented by Related Variety (RV), clustering, energy consumption, air pollution, and land use change (agriculture, vegetation, and built-up areas) indicators. The results of the study indicated that certain industries have contributed to unsustainability simultaneously; however, they had a high potential for economic synergy. Factors including the increase of industry production capacity, low technological level, and improper location of industrial parks and workshops in terms of economic synergy considerations, have led to increased distance among workshops and industrial parks in their supply and value chains. Therefore, for regional sustainable development, it would be prominent to employ cluster-based development according to RV and environmental policies including institutional transformation and innovative and green technologies.

## 1. Introduction

The phenomena of climate change, Greenhouse Gas Emissions (GHG), and global warming resulting from industrial activities and human activities are among the major challenges of today's world (Zhang & Farooq, 2023; Emami Javanmard & Ghaderi, 2022; Fawzy et al., 2020; Balsara et al., 2021). International accords like the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement have taken into consideration global efforts to mitigate the losses caused by these occurrences. However, the impacts of these changes are still prevalent (Kinley et al., 2021). Rapid urbanization and industrialization, along with extensive migrations from rural and small towns to large cities and metropolitan regions in developing countries, have created new environmental crises (Henderson & Turner, 2020; Pilehvar, 2021; Yousefi et al., 2022). Additionally, industrial development policies that primarily focus on the consolidation of industrial centers and the establishment of industrial parks and workshops, to leverage economies of scale and agglomeration, frequently overlook adequate consideration for environmental factors (Van Meeteren et al., 2016; Ye et al., 2019; Zheng et al., 2019; Liu et al., 2020; Delgado & Mills, 2020; B. Liu et al., 2023). Accordingly, cities and metropolitan regions have experienced alarming levels of environmental crises.

Hence, the sustainable development concept was proposed as a solution to reduce these problems. As a matter of fact, the sustainable development concept from the micro to the macro scale, especially at the regional level, has been the basis of policy-making and regional sustainable development and one of the most important policy-making issues for cooperation between the economic and ecological

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environment. In fact, the challenge of achieving a balanced economic and ecological development is known as one of the most important goals of sustainable regional development (Kang et al., 2021; Liu et al., 2022). Therefore, it can be said that an economy and an environment that are working together are necessary to achieve sustainable regional growth. When assets are combined, they create a far larger value than when they are apart. This is known as synergy (Hernandez & Menon, 2018; Hernandez & Shaver, 2019; Van den Berghe et al., 2023; Akbari et al., 2024).

Different studies have investigated the synergy between the economy and the environment from distinctive perspectives. Wolf et al. (2016) measured the economic models about their cost and benefit for the environment and emphasized the win-win strategy in the field of synergy between the economy and the environment concerning climate policy modeling. In another study, Chen et al. (2021) created an economic synergy in the Xia–Zhang–Quan metropolitan region based on the industries that have been investigated for economic growth and reduction in conservation of energy. Energy consumption and reduction of GHG with increasing employment and Gross domestic product (GDP) were another study that was implemented in the Chinese industries (Zhang et al., 2022). Therefore, they emphasize the synergy between policy-making goals toward achieving sustainable development. Yin and Xu (2022) have demonstrated the synergy between the economic development indices (i.e., scale, capabilities, and quality of economic development) and the ecological environment (eco-environmental level, system, and protection) in 26 cities in China and showed that there is no synergy between these indices. Yi et al. (2023) have evaluated the synergy between the economy, society, and environment to fulfil sustainable development. Xie et al. (2023) studied the synergy between economic development and the ecological environment quality in Suzhou Industrial Park, China, using satellite images. The results of their study indicate that the synergy between economic development, annual growth, and the ecological environment quality has suffered a gradual negative growth. In this context, scholars beleive that industrial pollution (i.e., Kolawole & Iyiola, 2023; Rifa & Hossain, 2022; Walker & Fequet, 2023), GHG emissions (e.g., Kelly et al., 2021; Kocak et al., 2023; Moreau et al., 2021), and energy consumption (such as Akadiri et al., 2022; Wang et al., 2021) serve as indicators of regional unsustainability in terms of economic expansion and environmental considerations.

These studies indicate that the economic synergy has been measured on a macro scale. Indeed, the resultant economic synergy has been evaluated, but the way and mechanism of the economic synergy formation have been neglected. In other words, it has not been addressed how the economic synergy is formed at the level of the region and among industries, what its measurement indices on a micro scale are, and how it is calculated. Different studies have indicated that economic synergy is associated with concepts such as cluster and the network inside and outside it, proximity and co-evolution, specialization, and diversification (Belso-Martínez et al., 2017; Zarghami et al., 2023). Especially, in the economic synergy concept at the regional level, the related variety (RV), was introduced in the last decade (Whittle & Kogler, 2019; Bathelt & Storper, 2023). The RV means that cognitive nearness is also necessary for industries to benefit from the presence of each other in addition to geographical proximity. For example, industries related to wood cannot be synergistic with the ones related to petrochemicals. Thus, an attempt has been made in this study to respond to the criticisms raised on this index by explaining the concept of RV as an index to measure the economic synergy among industries at the regional level, by modifying it. According to agglomeration theory, externalities are expected to be greater in areas with RV of sector than in areas with un-RV of sector diversity. One of these criticisms was related to the manner of knowledge and technology spillovers as the resultant economic synergy.

In addition, this is raised for the reason that the co-location and co-evolution affected by RV should provide the foundation of sustainability, besides creating an economic synergy. The concepts related to environmental economic geography are evaluated to investigate this issue. Environmental economic geography emphasizes the joint role of environmental factors, including regulations, environmental pollution, and resource elements, in economic activities. The focus of this theoretical approach was primarily on the relationship between industrial agglomeration and environmental pollution, and then, the keywords such as climate changes, sustainability, and governance were considered. The environmental economic geography is involved in the causes and contradictions of economic activities to adapt and respond to environmental changes. In other words, this approach investigates the interactions between economic activities and environment and the role of environmental regulations in economic activities (He et al., 2023). In this context, various scholars (i.e., Mu et al., 2022; Xie et al., 2023; Zhang et al., 2022) have offered their opinions. For example, Mu et al. (2022) analyzed the correlation and synergy of the urban economy-energy-environment system in Beijing. Their results showed that a fluctuating trend of little or no synergy is observed in Beijing. In addition, the upgrading of the energy subsystem led to the coordinated development of hybrid systems, and technological innovation and structural optimization in industries led to a better economy-energy-environment system in Beijing. Xie et al. (2023) developed a new model to evaluate environmental quality and a development index system to assess the economic status of Suzhou Industrial Park. Finally, they analyzed the relationship between environmental quality and economic development. Their results showed that the average annual growth rate of environmental quality has a downward trend, while the annual growth rate of economic development is increasing. Zhang et al. (2022) investigated Chinese economic industries using input-output analysis. Their model explored the synergies of sustainable development goals in maximizing economic benefits while minimizing natural resource usage, and pollutants to advance the sustainable industrial structure adjustment path. Their results showed that there are synergies between multiple objectives, e.g., minimizing emissions, and the trade-off between minimizing energy usage and maximizing employment.

There is various empirical evidence on the types of synergies, revenue synergies, cost synergies, and financial synergies. Revenue synergies arise from cross-selling products, entering new markets or geographies using the combined company's extended scope, developing new products by integrating capabilities, and increasing prices through increased pricing power and market access. Operational synergy is achieved by improving operational activities, such as reducing costs due to economies of scale. Financial synergies result from improved efficiency of financing activities and are primarily related to lower cost of capital. Therefore, one of the significant issues in metropolitan regions is to achieve economic synergy and sustainability simultaneously. Indeed, most policies are focused on how to achieve regional sustainability besides the economic synergy. This is also considered as one of the challenges of sustainable development in the Tehran metropolitan region (TMR). This region has become a place to attract economic activities, especially industrial ones, in recent decades. Furthermore, creating favorable economic opportunities, TMR faced many environmental problems (including the formation of heat islands in urban centers, high levels of air pollution, production, and emission of GHG, and formation of zones such as methane gas in the south of the region). The industries of TMR are evaluated in this study. Accordingly, the main goal of the study is how to create synergy between the economy and the environment in TMR; the sub-goals of which include:

a) measuring the status of economic synergy between industries,
b) assessing the metropolitan region's environmental state, and
c) attaining sustainable regional development by simultaneously reducing environmental harm and increasing economic synergies.

Hence, the fundamental challenge in achieving sustainable development in this region has consistently been the contradiction between economic growth and regional stability. As a result, the following are the research questions:

1) What is the status of the economic synergy of industries and environmental sustainability in TMR?
2) How is the synergy between the economy and the environment realized?

## 2. Theoretical foundations

The concept of synergy has been introduced in regional economics studies in the last two decades, and the development of synergy in the regional economy is the process of interaction and integration of diverse economic subsystems at the regional level (Chen et al., 2021). The application of economic synergy in studies related to metropolitan regions has been instrumental in addressing regional imbalances and achieving regional sustainable economic and industrial development (Wang & Meng, 2020; Chen et al., 2021; Ding et al., 2022; Chen & Wu, 2022; Miani et al., 2023). Synergy at the regional level relates to concepts such as unsustainability, cooperation, proximity, integration, gap, economic growth, and taking collaborative advantages. Therefore, it is essential to concentrate on spatial analyses, theories and approaches that explain the mechanisms of economic synergy. Economic geography is one such theoretical foundation for a better understanding of the dynamics and processes of economic synergy, especially at the industrial level. Although economic geography has not specifically focused on economic synergy, the investigation of its theoretical foundations provides an improved comprehension of the economic synergy's process and outcome. Therefore, this study first investigates the synergy concept from the viewpoint of new economic geography (NEG).

NEG is a field that analyzes regional economic disparities based on spatial agglomeration effects (McCann & Van Oort, 2019). It focuses on centripetal and centrifugal forces as important factors in industrial concentration or distribution and recognizes spatial agglomeration as the factor behind regional growth and the formation of industrial clusters, due to what is known as Marshallian externalities (Hassink et al., 2019; Gong & Hassink, 2019; Oliveira et al., 2022). According to Du and Vanino (2021), Stojčić et al. (2022), knowledge and technology spillovers, backward and forward linkages, vertical integration of firms, and specialized labor markets are the ways in which spatial agglomeration takes shape and gives rise to these externalities. They may be viewed collectively as a type of economic synergy that might result in the specialization of industrial processes. In actuality, the NEG takes note of the fact that economies of scale and agglomeration lead to the spatial concentration of businesses and that these businesses form clusters through their proximity and co-location, which in turn leads to the formation of intra- and extra-cluster networks. New spatial agglomerations of enterprises are formed due to issues such as the pressure of competition as time passes.

In contrast, evolutionary economic geography (EEG) emphasizes the role of variety. The logic behind this perspective is that spatial agglomeration leads to externalities only when variety exists in industrial activities. EEG points to the fact that not every proximity or co-location leads to the creation of knowledge, technology spillovers, the formation of clusters, and their internal and external interfaces. Indeed, the supporters of the approach of the economic geography believe that the concentration in the enterprise geography leads to the enterprises' co-evolution in the long term. NEG only considers geographic proximity as a positive factor in creating synergy; however, this issue has been criticized by EEG because of ignoring the proximity paradox which contains the involuntary knowledge spillovers and the imitation process (Kogler et al., 2023). The EEG does not consider the variety to create synergy and emphasizes the RV concept by re-criticizing the diversification.

NEG and EEG approaches have mainly analyzed the economic situation and the environmental importance has not been taken into consideration. The link between the environment and the economy is the focus of environmental economic geography. In actuality, it aims to respond to questions about how environmental constraints limit economic activities, how economic activities create environmental effects, and how environmental changes affect economic activities. Understanding the reciprocal effects of the geographical distribution and concentration of economic activity on the environment and the economy is the general aim of environmental economic geography (Braun et al., 2018; He et al., 2022). Hence, environmental changes, degradation, and policies are recognized as three axes related to environmental economic geography. This approach refers to the fact that parallel to the concentration of industrial activities in a place, its negative environmental effects are not specific to that place but they affect other places as well. However, the spatial concentration of industrial activities may lead to specialization or diversification, whose environmental effects can also be different. This approach emphasizes the point that the concentration level of industrial activities is not influential in terms of creating environmental problems, and the spatial organization and structural transformation of the activities' concentration are influential in this issue.

## 3. Methodology

### 3.1. Study area

With 16,999,400 residents, the 2022TMR accounts for around 20 % of the total population of the nation and is made up of 66 cities and 22 counties (Statistical Centre of Iran, 2023). The concentration of industrial facilities in this area has earned it the title of Iran's economic center. This area is made up of 4 industrial zones, 17 municipalities, and 12,944 industrial enterprises and workshops. According to the Ministry of Industry, Mines, and Trade and the Statistics Center of Iran, the value added of Iran's economy in the metropolitan region is divided into the following economic sectors: mining, agriculture, construction, industry, and services, with corresponding shares of 37.96, 25.54, 24.7, and 0.43 % in 2000–2022 (Fig. 1).

### 3.2. Design

To measure economic synergy, a two-part formula based on RV has been used. First, the amount of industrial diversity is determined; next, the industries' relative values (RVs) are examined; and finally, their sustainability is appraised. In related studies on measuring diversity, the main focus has been on measuring regional diversity (Kopczewska, 2017; Balland et al., 2018). Generally, measuring RV is based on the products produced in a group or the products related to a cluster, or based on the proximity of industries at a specific distance (Boschma & Capone, 2015; Content & Frenken, 2016). These studies have neglected some aspects of RV, whereas the number of firms and industries in each category related to the International Standard Industrial Classification (ISIC) code is essential for creating synergy. Moreover, forward and backward linkages among these industries and firms have been overlooked. Therefore, this study modified these imperfections as mathematical bases and would be applicable to policy-makers, investors, and scientific societies.

In this study, RV variable data (Table 1) has been collected since 2000–2022. To identify the linkages between industries, data from the input-output model was used based on the Statistical Center of Iran. The input-output model was analyzed using the supply-driven Ghosh model and the demand-driven Leontief model. Leontief's demand-driven model shows the effects of final demand on the production structure of different sectors of the economy. In fact, it shows the average direct and indirect intermediary needs of each activity in a unit of final demand. Ghosh's supply-driven model reveals the potential changes of the primary factors in the production system and the aim is to establish a constructive relationship between the primary factors (value added) and

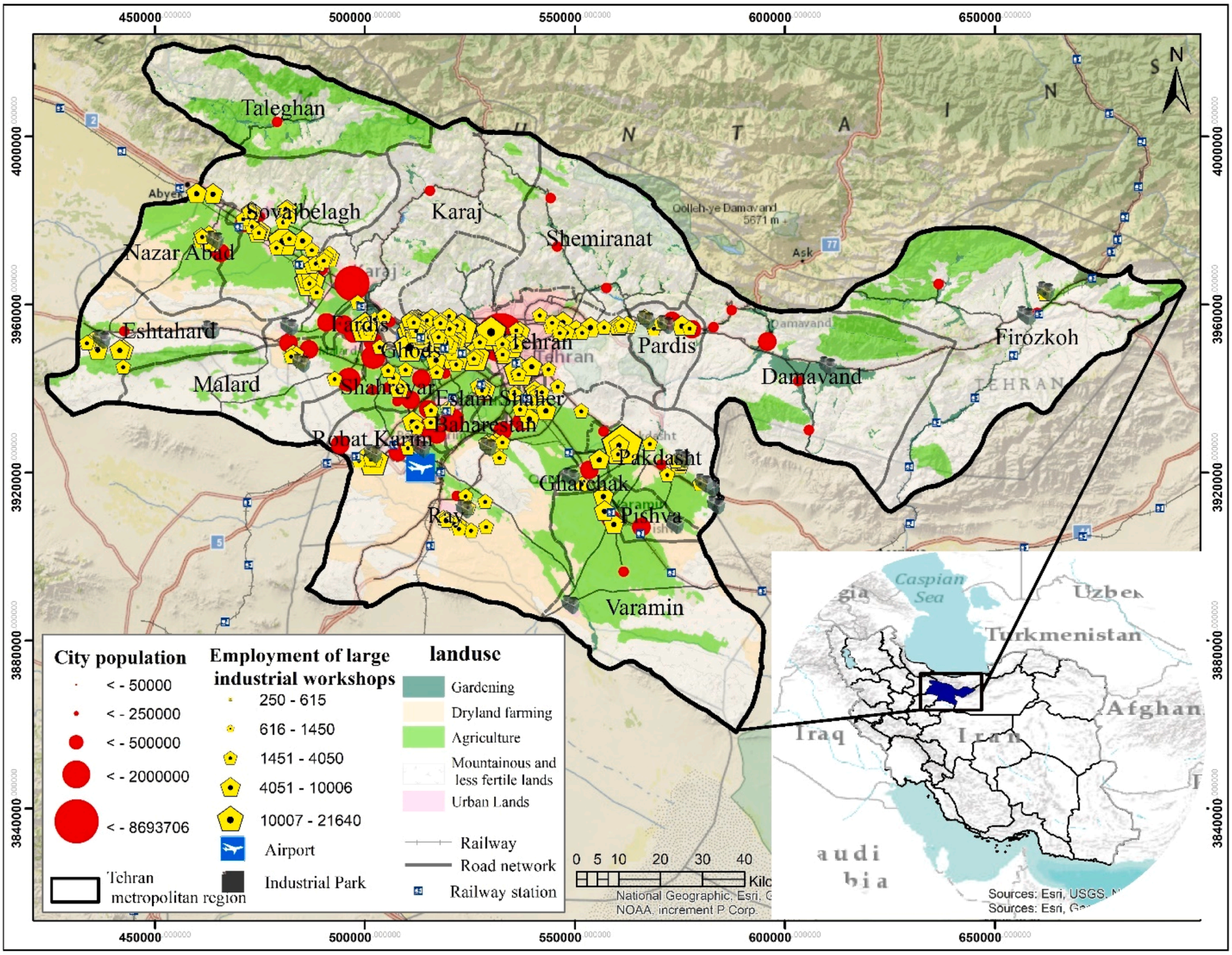


**Fig. 1.** Spatial structure of TMR.

the production system in such methods.

### 3.2.1. Related variety

The RV coefficient ranges from zero to infinity. The higher the coefficient, the greater the RV in that industry will be. This formula consists of three parts. In the first section, $K_{ij}$ refers to the number of subsets of an industry. For instance, Table 1 indicates that there are 15 subgroups in the manufacturing of food and beverage items. $S_{ij}$ refers to the employment rate of industries in the entire region, which is equivalent to 67,926 people for this industry. The next one is the index $F_{ij}$, which shows the number of workshops by industry. For example, TMR has 1373 industrial workshops that are involved in the production of food and drink items. Consequently, the following is the RV formula.

$$RV = \sum_{i=1}^{n} \left[K_{ij} + S_{ij} + F_{ij}\right].\ LQ.\ (DIBL_n\ .\ DIFL_n) \tag{1}$$

$$K_{ij} = \frac{industry_{ij}}{\sum_i industry_{ij}} \text{ The quantity of industry i sub} - \text{indices in region j.} \tag{2}$$

$$S_{ij} = \frac{emp_{ij}}{\sum_i emp_{ij}} \text{ Employment percentage in area j for industry i.} \tag{3}$$

$$F_{ij} = \frac{firm_{ij}}{\sum_i firm_{ij}} \text{ The number of workshops in area j for industry i.} \tag{4}$$

### 3.2.2. Location quotient

The LQ formula is calculated in the second section. This section refers to the export-oriented industries. LQ coefficient shows that if its coefficient is higher than one, then it means that the industry is export-oriented, and if it is less than one, then it means that this industry is dependent (Kopczewska et al., 2017).

$$LQ = \frac{S_{ij}^s}{S_i} = \frac{emp_{ij} \Big/ \sum_i emp_{ij}}{\sum_i emp_{ij} \Big/ \sum_i \sum_j emp_{ij}} \tag{5}$$

$$S_{ij} = \frac{emp_{ij}}{\sum_i emp_{ij}} \tag{6}$$

$S_{ij}$ is the proportion of employment in region j's sector I to overall employment (across all sectors) in that region.

$$S_i = \frac{\sum_j emp_{ij}}{\sum_i \sum_j emp_{ij}} \tag{7}$$

$S_i$ is the proportion of overall employment (all i sectors in all j regions) to sector i employment in all j regions. The third section measures forward and backward linkages to assess the spatial connections

**Table 1**
Industries based on TMR's 28 ISIC codes; The Ministry of Industry, Mining, and Trade and the Iranian Statistical Center provided this data.

| ISIC codes for industry | The number of industry types | The number of industrial employments | The number of workshops | ISIC codes for industry | The number of industry types | The number of industrial employments | The number of workshops |
|---|---|---|---|---|---|---|---|
| Mining of ferrous metal ores (13) | 2 | 97 | 2 | Manufacture of basic metals (27) | 4 | 19,659 | 799 |
| Mining and quarrying (14) | 2 | 680 | 30 | Manufacture of fabricated metal products, except machinery and equipment (28) | 7 | 42,188 | 1598 |
| Manufacture of food products and beverages (15) | 15 | 67,926 | 1373 | Manufacture of machinery and equipment n.e.c. (29) | 14 | 61,908 | 1403 |
| Manufacture of tobacco products (16) | 1 | 3508 | 47 | Manufacture of office, accounting, and computing machinery (30) | 1 | 6253 | 86 |
| Manufacture of textiles (17) | 7 | 16,389 | 477 | Manufacture of electrical machinery and apparatus n.e.c. (31) | 6 | 27,018 | 422 |
| Manufacture of wearing apparel, dressing, and dyeing of fur (18) | 1 | 5473 | 132 | Manufacture of radio, television, and communication equipment and apparatus (32) | 3 | 11,182 | 139 |
| Tanning and dressing of leather: manufacture of luggage, handbags, saddlery, harness, and footwear (19) | 3 | 6463 | 137 | Manufacture of medical, precision, and optical instruments; watches; and clocks (33) | 5 | 12,180 | 298 |
| Manufacture of wood and products of wood and cork, except furniture (20) | 1 | 3639 | 149 | Manufacture of motor vehicles, trailers, and semi-trailers (34) | 3 | 76,317 | 348 |
| Manufacture of paper and paper products (21) | 3 | 7614 | 240 | Manufacture of other transport equipment (35) | 6 | 5916 | 76 |
| Publishing, printing, and reproduction of recorded media (22) | 4 | 2977 | 50 | Manufacture of furniture and manufacturing n.e.c. (36) | 5 | 7524 | 245 |
| Manufacture of coke, refined petroleum products, and nuclear fuel (23) | 2 | 5271 | 121 | Recycling (37) | 2 | 2048 | 73 |
| Manufacture of chemicals and chemical products (24) | 9 | 46,027 | 1115 | Electricity, gas, steam, and hot water supply (40) | 1 | 45 | 1 |
| Manufacture of rubber and plastics products (25) | 3 | 36,357 | 1375 | Construction (45) | 1 | 6942 | 748 |
| Manufacture of other non-metallic mineral products (26) | 8 | 34,091 | 1079 | Supporting and auxiliary transport activities and activities of travel agencies (63) | 1 | 404 | 20 |

between industries and the spillovers of knowledge and technology, with results presented in Table 3.

### 3.2.3. Spatial linkages (backward and forward linkages)

The inverse Leontief matrix $\left(I-\breve{A}\right)^{-1}$, which represents the direct and indirect production chain effects for a unit increase in the final demand of a region, expresses the increase in production of the sectors in the same region and other regions. Assuming this hypothesis, $\left(I-\breve{A}\right)^{-1}$, and considering the economy in two regions A and B, equation (8) will be a matrix as follows:

$$\Delta X = a_{ij}\Delta X_i \begin{bmatrix} \Delta X_i^B \\ \Delta X_i^A \end{bmatrix} = \begin{bmatrix} a_{ij}^{BA} & a_{ij}^{BA} \\ a_{ij}^{AB} & a_{ij}^{AA} \end{bmatrix} \begin{bmatrix} \Delta X_i^B \\ \Delta X_i^A \end{bmatrix} \tag{8}$$

Equation (8) shows to what extent a unit increase in investment in one of the economic sectors in region B results in a direct and indirect increase in production in the same sector in region A. Therefore, the following equation is used to measure direct and indirect backward linkages of sectors:

$$BIBL_j^B = e_i' a_{ij}^{BR} \Delta Y_i^B \ R = B,\ A \tag{9}$$

$$BIBL_j^A = e_i' a_{ij}^{AR} \Delta Y_i^A \ R = B,\ A \tag{10}$$

where, $BIBL_j^A$, and $BIBL_j^B$ represent the direct and indirect backward linkages of sector j in regions B and A, respectively and $e_i'$ is a unit row-summing vector of the matrix. Direct and indirect backward linkages can be distinguished as inter-regional linkages. Eq. (11) represents direct and indirect backward linkages. The following equation is used to measure direct and indirect backward linkages:

$$e_j' = \sum_i Z_{ij} + VA_j' \tag{11}$$

The supply-driven coefficient matrix is also as follows:

$$b_{ij} = Z_{ij}/X_i \tag{12}$$

In Eq. (12), $b_{ij}$ shows the extent to which sector i directly sells a unit of its production to other economic sectors for a unit of its own production. According to the Ghosh supply-driven model, the production balance is as follows:

$$X' = X'B + VA' \quad X' = VA'(I-B)^{-1} \tag{13}$$

In this equation, $(I-B)^{-1}$ is known as the Ghosh inverse matrix. In the case of two regions, the equation is as follows:

$$\Delta X_j' = \Delta VA_j' B_{ij} \begin{bmatrix} \Delta X_i^B & \Delta X_i^A \end{bmatrix} = \begin{bmatrix} \Delta XA_i^B & \Delta XA_i^A \end{bmatrix} \begin{bmatrix} B_{ij}^{BB} & B_{ij}^{BA} \\ B_{ij}^{AB} & B_{ij}^{AA} \end{bmatrix} \tag{14}$$

The direct and indirect impacts of an increase in sector j's value-added in region B on an increase in output in the same sector in region A are outlined in Eq. (14). Accordingly, direct and indirect forward linkages for two regions A and B are as follows:

$$DIFL^{B} = \Delta VA_{j}^{B} B_{ij}^{RB} e_{i} \; R = B, \; A \tag{15}$$

$$DIFL^{BA} = \Delta VA_{j}^{A} B_{ij}^{RA} e_{i} \; R = B, \; A \tag{16}$$

To simplify the ranking of the importance of sectors in the region, analysts use the normalized criterion. Eq. (17) normalizes backward linkages, and Eq. (18) normalizes forward linkages, where n is the number of sectors. Key industries are identified through normalized backward and forward linkages with values higher than other sectors (Manresa & Sancho Aroche, 2020; Reyes & Marquez Mendoza, 2021; Oosterhaven & Hewings, 2021).

$$DIBL_{n} = \frac{\frac{1}{n}\sum_{i=1}^{n}(I-A)^{-1}}{\frac{1}{n^{2}}\sum_{i=1}^{n}\sum_{j=1}^{n}(I-A)^{-1}} \tag{17}$$

$$DIBL_{n} = \frac{\frac{1}{n}\sum_{i=1}^{n}(I-A)^{-1}}{\frac{1}{n^{2}}\sum_{i=1}^{n}\sum_{j=1}^{n}(I-A)^{-1}} \tag{18}$$

#### 3.2.4. Clustering

Using the gravity model, this index looks at the employment share in sectors and areas and considers how much weight each sector has in relation to the distance between regions geographically:

$$C_{n} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m}\left(\frac{y_{i}^{n}\ y_{j}^{n}}{d_{ij}}\right)}{\sum_{i=1}^{m}\sum_{i=1}^{m}\left(\frac{y_{i}y_{j}}{d_{ij}}\right)} \tag{19}$$

$d_{ij}$ = the distance between regions
$y_i y_j$ = the regions' share of employment
$y_i^n\ y_j^n$ = share of the sector's industry from the total employment of sectors and regions
$I, j$ = regions
m = industrial sectors

The clustering index ranges from zero to infinity. In other words, the higher the clustering coefficient tends towards a higher number, the more it indicates the clustering of activity at the spatial level (Kopczewska et al., 2017). To measure the clustering of activities, the industrial workshop coordinate system is first entered into the SAS Planet software to measure the precise location of industrial workshops. The output was then entered into the Arc Map software for spatial analysis.

To measure regional sustainability, the amount of energy consumption, air pollution, and land use change were evaluated. To examine land use changes, Landsat TM 5 and 8 satellite images were obtained from USGS for the years 1998 and 2020. When obtaining images, the angle of solar radiation, agricultural seasons, and cloud cover were considered. In the preprocessing stage, top of atmosphere (TOA) was applied to reduce the effects of solar radiation angle, and the dark object subtraction (DOS) method was used to correct radiometric errors. The supervised classification method of ENVI 5.3 software was used to classify the images. Thus, five primary land use classes were defined, and then the 6 × 6 filtering method was used to reduce errors.

## 4. Results

### 4.1. Assessing related variety

The main analyses in the field of assessing RV are based on the perspective of EEG. This perspective challenges the idea of diversity and its impact on regional growth and development. It means that not every type of diversity leads to knowledge spillovers and that RV should be related to the basic structure of the region's activity system. In other words, external economies of RV between local firms are considered positive due to knowledge spillovers and the mobility of skilled labor. Intra-industry externalities negatively impact local firms due to competitive pressure and unintentional knowledge spillovers (Boschma, 2015; Boschma & Frenken, 2018). Additionally, EEG raises the issue of networking externalities among firms, not only through clustering and proximity but also through "cognitive proximity", which can be considered a form of RV (Balland et al., 2015).

Table 2 demonstrates that industries producing rubber and plastic products, food products and beverages, other non-metallic mineral products, machinery and equipment, chemicals and chemical products, and fabricated metal products outside of machinery and equipment have higher RV coefficients. To measure the knowledge spillovers between these industries, backward linkages have been evaluated. The presence of a high coefficient of backward linkage means that these industries are considered upstream and their production is available as inputs to other producers. In fact, by establishing these industries in any region, they provide a basis for vertical integration among workshops. This coefficient also shows that industries with a high RV coefficient have a high backward linkage. Furthermore, it is examined to what extent industries with a high RV coefficient have tended towards spatial clustering. The presence of both backward and forward linkages alongside geographical proximity facilitates economic synergy, which is discussed in the clustering section.

### 4.2. Clustering

Table 3 indicates that out of 28 industrial activities in the TMR, 10 industries have formed spatial clusters. Manufacturers producing machinery and equipment, non-metallic mineral goods, and food and beverage items have the greatest clustering coefficient. These industries not only have a high RV coefficient but also have a higher clustering coefficient compared to other industries and have formed spatial clusters in the TMR.

As shown in Fig. 2, nine clustered industries are located in Tehran County. Many industries have used illustrations, including Savajbelagh County's food and beverage items, medical, precise, and optical instruments, watches, and clocks. It can be stated that industries with a high RV coefficient have also formed clusters in the TMR.

According to the statistics in Table 4, the industries that produce motor vehicles, trailers, and semi-trailers contribute significantly to the nation's value-added output. In other words, clustered industries with a high RV coefficient are key and influential industries in the economic growth of the TMR. The cause of some industries' high value-added output (e.g., publishing, printing, recording media replication, the manufacturing of office, accounting, and computer equipment) is the geographical concentration of these industries in the TMR and these industries' lack of development in other parts of the country. In general, the ten industries with high clustering coefficients and RV account for a significant share of employment and value-added output. In fact, these industries are recognized as key industries that have a high share in economic growth and have a high potential for creating economic synergy.

### 4.3. Regional sustainability assessment

#### 4.3.1. Greenhouse gas emissions (air pollution)

According to Table 5, about 76.9 million tons of GHG were emitted from the consumption of fossil fuels in 2022. It had a 118.6 % growth compared to 2012. The transportation sector is the most important emitter of GHG, with a share of more than 50 %. However, in 2012, the household sector was the most important emitter of GHG in the TMR,

**Table 2**
Measuring RV of industries in TMR.

| ISIC code | V | L.Q | Normalized backward linkage coefficient | Normalized Forward linkage coefficient | VR coefficient | ISIC code | V | L.Q | Normalized backward linkage coefficient | Normalized Forward linkage coefficient | RV coefficient |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 0.016 | 0.796 | 0.921 | 0.927 | 0.011 | 27 | 0.130 | 0.834 | 2.010 | 0.972 | 0.211 |
| 14 | 0.019 | 0.954 | 0.816 | 0.877 | 0.013 | 28 | 0.257 | 0.869 | 1.169 | 0.953 | 0.249 |
| 15 | 0.350 | 1.436 | 3.486 | 0.919 | 1.612 | 29 | 0.334 | 0.819 | 1.160 | 1.160 | 0.368 |
| 16 | 0.018 | 0.304 | 0.953 | 0.764 | 0.004 | 30 | 0.026 | 0.622 | 0.968 | 0.973 | 0.015 |
| 17 | 0.122 | 0.941 | 1.035 | 1.213 | 0.145 | 31 | 0.130 | 1.132 | 1.115 | 0.895 | 0.147 |
| 18 | 0.028 | 1.528 | 1.037 | 1.182 | 0.053 | 32 | 0.055 | 0.732 | 1.103 | 0.897 | 0.040 |
| 19 | 0.046 | 1.262 | 1.220 | 1.147 | 0.082 | 33 | 0.085 | 0.737 | 1.270 | 0.978 | 0.078 |
| 20 | 0.026 | 1.209 | 0.897 | 0.979 | 0.028 | 34 | 0.192 | 0.401 | 1.506 | 1.232 | 0.143 |
| 21 | 0.056 | 0.989 | 1.122 | 1.450 | 0.091 | 35 | 0.064 | 0.640 | 1.013 | 1.273 | 0.053 |
| 22 | 0.041 | 0.433 | 1.075 | 1.189 | 0.023 | 36 | 0.072 | 1.143 | 1.160 | 1.330 | 0.127 |
| 23 | 0.035 | 0.853 | 1.044 | 1.187 | 0.037 | 37 | 0.025 | 0.748 | 1.098 | 0.913 | 0.019 |
| 24 | 0.242 | 0.993 | 1.049 | 1.134 | 0.287 | 40 | 0.008 | 0.142 | 0.804 | 1.099 | 0.001 |
| 25 | 0.197 | 1.001 | 1.145 | 1.272 | 0.288 | 45 | 0.079 | 0.811 | 1.100 | 0.606 | 0.042 |
| 26 | 0.210 | 2.657 | 1.026 | 1.064 | 0.608 | 63 | 0.010 | 3.160 | 0.896 | 1.059 | 0.030 |

**Table 3**
Clustering coefficient of industrial activities in TMR.

| ISIC code | Clustering coefficient | Observed Mean Distance (Meters) | Expected Mean Distance (Meters) | Nearest Neighbor Ratio | z-score | p-value |
|---|---|---|---|---|---|---|
| 15 | 5.672 | 609.32 | 2074.72 | 0.2936 | −50.43 | 0.000 |
| 17 | 0.506 | 1382.71 | 3850.00 | 0.3591 | −23.61 | 0.000 |
| 24 | 0.894 | 784.74 | 2697.52 | 0.2909 | −37.83 | 0.000 |
| 25 | 0.712 | 685.88 | 2343.01 | 0.2812 | −41.79 | 0.000 |
| 26 | 2.570 | 809.76 | 2470.97 | 0.3277 | −40.20 | 0.000 |
| 28 | 1.225 | 602.20 | 2257.86 | 0.2667 | −45.97 | 0.000 |
| 29 | 2.154 | 650.87 | 2084.46 | 0.3122 | −43.23 | 0.000 |
| 31 | 1.861 | 1287.03 | 3457.72 | 0.3722 | −23.50 | 0.000 |
| 33 | 0.514 | 1762.87 | 3699.28 | 0.4765 | −14.54 | 0.000 |
| 34 | 0.486 | 1161.27 | 2803.61 | 0.4142 | −19.14 | 0.000 |

with a share of more than 42 %. The most important GHG emitted is $CO_2$, which accounts for over 96 % of the gases and has not changed significantly since 2012. Although the emission of this type of gas has increased in all sectors, the transportation and industrial sectors have an upward trend in their emission, while it is downward in other sectors.

The investigation of GHG emissions by the industrial sector shows that the total GHG emissions in the industrial sector reached from 7.22 million tons in 2012 to 8.83 million tons in 2022. This sector, with a share of 33.92 %, is the third-largest emitter of GHG in TMR, after transportation with 50.19 % and household with 33.92 %. Fig. 3 presents that among the emitted industrial gases, $SO_2$ and $SO_3$ had the highest emissions, and the lowest level of emission in the industrial sector was related to CO with 0.02 %. The per capita GHG emission in the TMR in 2022 shows that each person emits 5086 kg of GHG annually, and it has grown more than 104 % since 2012. The investigation of the industrial sector shows that in 2012, this per capita emission was 236 kg per person, which reached 448.9 kg in 2022.

The level of air pollution in the TMR -according to the Department of Environment in Iran- is shown in Table 6 based on the quality index measured by 33 air quality monitoring centers in six categories. Based on this, pollutants levels in the air for the years 2021 and 2022 have been in a dangerous state; in other words, the pollution level has been 300 or higher for seven days throughout the year. From Table 6, the results showed that on average, 104 days of dangerous air quality for sensitive groups, 13 days were in unhealthy and 22 days were in clean situations yearly.

Next, the index measuring sustainability based on energy consumption by industries is evaluated.

*4.3.2. Energy consumption*

To examine energy consumption, the amount of consumption was evaluated in industrial workshops in the fields of white oil, diesel, liquefied gas, natural gas, gasoline, black oil, furnace oil, coal, wood coal, other fuel materials, electricity, and water. The study of energy consumption in the industries of the TMR shows that on average, this region has had a 10.17 % share of the country's total energy consumption during the studied years and is ranked fourth among the provinces of the country according to the report of the Ministry of Energy of Iran. Fig. 4 displays the energy consumption of various industries broken down by category. The manufacturing of food items and drinks, refined petroleum, and other non-metallic mineral products have the largest energy consumption. Electricity, natural gas, and water have the highest energy consumption in the top five energy-consuming industries, respectively.

The analysis of energy carriers shows that electricity with 60.31 % has the highest energy consumption in industrial workshops in the TMR. At first glance, this amount means a reduction in environmental pollution because electricity consumption has the lowest amount of air pollution production. However, it should be noted that thermal power plants use fossil fuels, and in some cases, burn Mazut to generate electricity. Therefore, increasing electricity consumption increases air pollution. Natural gas with 25.58 % is in second place, and water with 4.88 % is in third place among the energy consumption of industrial workshops in TMR.

*4.3.3. Land use change*

Table 7 and Fig. 5 display the final findings of the investigation of changes in land cover. As is evident, in agricultural lands and densely vegetated areas, there has been a decrease due to the extension of construction areas in agricultural lands from 1998 to 2020. During this period, constructed areas have almost doubled, and due to their location in the heart of fertile agricultural lands, the amount of these lands has decreased. It is noteworthy that the increase in water area of the region is mainly due to water storage behind dams.

Overall, land use changes in the TMR during the studied period show that the share of agricultural and vegetated areas has decreased as a result of the development of constructions on the outskirts of cities and the trend of urbanization and industrial expansion, which will lead to the long-term unsustainability of the TMR. Therefore, in the next section, the contradiction between economic growth and regional unsustainability will be discussed.

## 5. Discussion

There is always a debate among researchers that the economic synergy occurs from the path of specialization or diversity. One group of researchers (e.g., Ivanova et al., 2019; Kemeny & Storper, 2015; Tavassoli & Jienwatcharamongkhol, 2016; Henning, 2019; Pei et al., 2021; Martin & Sunley, 2022) believes that specialization is highly

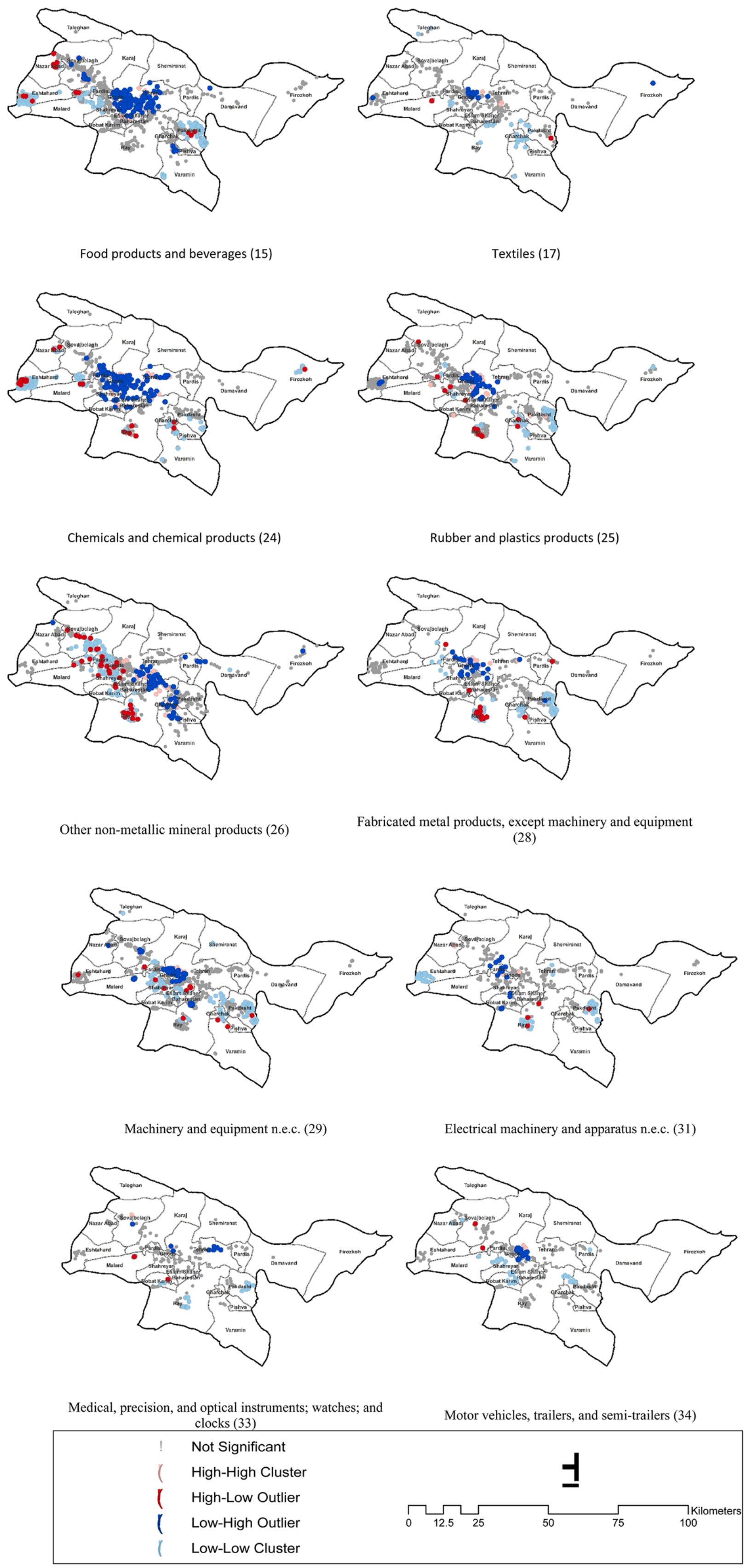


**Fig. 2.** Clustering industries in TMR.

**Table 4**
Performance of sectors in the TMR from 2002 to 2022 in terms of creating jobs and adding value to production.

| ISIC code | Percentage of contribution to national value-added | Direct employment coefficient | Indirect employment coefficient | ISIC code | Percentage of contribution to national value-added | Direct employment coefficient | Indirect employment coefficient |
|---|---|---|---|---|---|---|---|
| 13 | 0.43 | 0.000007 | 0.000005 | 27 | 4.89 | 0.0008578 | 0.000224 |
| 14 | 1.03 | 0.000044 | 0.000004 | 28 | 34 | 0.0009304 | 0.000193 |
| 15 | 21.88 | 0.000512 | 0.000169 | 29 | 38.47 | 0.0020191 | 0.000311 |
| 16 | 36.32 | 0.004487 | 0.000134 | 30 | 56.91 | 0.0013383 | 0.000170 |
| 17 | 12.10 | 0.001856 | 0.000265 | 31 | 33.61 | 0.002407 | 0.000380 |
| 18 | 49.94 | 0.001485 | 0.000341 | 32 | 40.23 | 0.001951 | 0.000372 |
| 19 | 50.23 | 0.001202 | 0.000408 | 33 | 45.65 | 0.002512 | 0.0004822 |
| 20 | 25.21 | 0.008005 | 0.000146 | 34 | 66.90 | 0.0006146 | 0.0003917 |
| 21 | 26.34 | 0.001299 | 0.000232 | 35 | 32.10 | 0.0010788 | 0.0001620 |
| 22 | 62.60 | 0.000401 | 0.000003 | 36 | 47.40 | 0.0005690 | 0.0002825 |
| 23 | 22.69 | 0.000111 | 0.000007 | 37 | 9.98 | 0.0005317 | 0.0002540 |
| 24 | 12.46 | 0.000756 | 0.000009 | 40 | 20.73 | 0.0000001 | 0.0000001 |
| 25 | 30.57 | 0.001552 | 0.000294 | 45 | 24.27 | 0.0002158 | 0.0001593 |
| 26 | 13.51 | 0.0014402 | 0.000107 | 63 | 10.64 | 0.0000003 | 0.0000001 |

**Table 5**
The share of each sector in GHG emissions in the TMR (tons). This data was collected from the Ministry of Energy and the Department of Environment in Iran.

| | **$NO_x$** | | **$SO_2$** | | **$SO_3$** | | **CO** | |
|---|---|---|---|---|---|---|---|---|
| | 2012 | 2022 | 2012 | 2022 | 2012 | 2022 | 2012 | 2022 |
| Household | 14,258.6 | 25,004.1 | 21,840.6 | 813.3 | 239.4 | 7.3 | 4213 | 3274.8 |
| Commerce | 5876.8 | 4664.2 | 19,967.2 | 1566.7 | 287.6 | 23.4 | 1222 | 582 |
| Agriculture | 2868 | 2466 | 2947.4 | 2085.7 | 17.9 | 12.7 | 661.4 | 503.2 |
| Industry | 5702.6 | 11,486.6 | 25,132.2 | 4502.4 | 368.2 | 64.7 | 203 | 440.6 |
| Transportation | 88,780 | 125,950.8 | 35,191.3 | 37,763.8 | 1001.2 | 939.4 | 1,104,623.8 | 2,144,022.6 |
| Total | 117,485.9 | 169,571.7 | 105,078.8 | 46,732 | 1914.3 | 1047.5 | 1,110,923.2 | 2,148,923.1 |
| | SPM | | **$CO_2$** | | **$CH_4$** | | **$N_2O$** | |
| | 2012 | 2022 | 2012 | 2022 | 2012 | 2022 | 2012 | 2022 |
| Household | 1906.2 | 2404.2 | 15,644,003.1 | 27,062,294 | 431.8 | 488.3 | 70.2 | 49.8 |
| Commerce | 686.6 | 449.9 | 3,663,756.2 | 4,796,245.3 | 116.4 | 88/1 | 65.9 | 9.3 |
| Agriculture | 1252.1 | 929.4 | 533,221.8 | 831,799.7 | 28/9 | 28/5 | 194.7 | 138.8 |
| Industry | 764.8 | 1076.1 | 2,605,851.4 | 7,030,796 | 103.5 | 135/6 | 20.6 | 3.8 |
| Transportation | 27,285.8 | 66,616.3 | 12,706,732.5 | 37,691,400.9 | 4009.3 | 14,361/7 | 672.9 | 1753.1 |
| Total | 31,895.6 | 71,475.9 | 35,153,564.9 | 77,412,535.9 | 4690 | 15,102/2 | 1024.1 | 1954.8 |

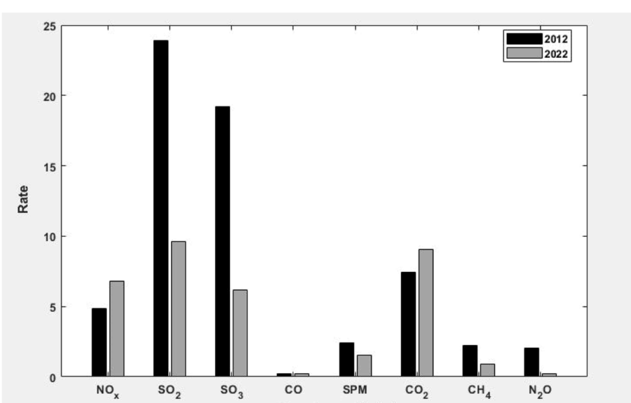


**Fig. 3.** The level of GHG.

effective in creating synergy by utilizing the local economy. Relying on the viewpoints of EEG, another group considers diversification effective in fostering synergy within the urban economy (e.g. Kashiwagi & Iwasaki, 2023). Furthermore, the study conducted by Zarghami et al. (2023) in TMR mentioned diversity as a key element in fostering regional economic synergy and has suggested that diversification causes economic resilience (Tan et al., 2020) against the economic crisis through the knowledge and technology spillover, innovation, recombination, and new path creation, but it must be considered what kind of diversification causes the creation of more economic synergy in order to create synergy among the economic sectors. Evolutionary economists have introduced the concept of RV, presenting a new challenge in the field of relevant diversification by introducing the concept of related diversification or diversified specialization (Bathelt & Storper, 2023).

Numerous studies have highlighted the factors contributing to synergy creation (Lazzeretti et al., 2017; Basile et al., 2017; Firgo & Mayerhofer, 2018; Howell et al., 2018; Miguelez & Moreno, 2018; Content et al., 2019; Van Oort et al., 2015). The majority of these studies

**Table 6**
Air quality index measurement based on days per year in the TMR.

| AQI | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hazardous 301 and higher | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| Very Unhealthy 201 t0 300 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| Unhealthy 151 to 200 | 14 | 5 | 9 | 13 | 5 | 2 | 14 | 19 | 17 | 27 | 22 |
| Unhealthy for Sensitive Groupe 101 to 150 | 131 | 107 | 100 | 79 | 90 | 45 | 87 | 92 | 133 | 138 | 142 |
| Moderate 51 to 1oo | 207 | 224 | 235 | 251 | 246 | 273 | 223 | 232 | 209 | 187 | 190 |
| Good 0 to 50 | 13 | 29 | 19 | 22 | 24 | 45 | 41 | 22 | 6 | 8 | 4 |

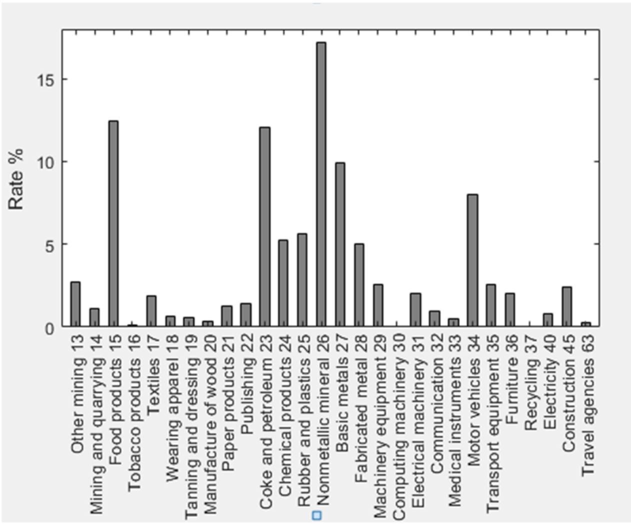


**Fig. 4.** Share of industries in energy consumption during the years 2002 to 2022 in the TMR based on the data of management and planning organization of Tehran.

**Table 7**
Land use changes during the period of 1998 to 2020 in the TMR.

| Category | 1998 | 2020 | Percentage change |
|---|---|---|---|
| Water sources | 1099.44 | 3016.44 | 174.4 |
| Built up areas | 12,056.3 | 180,431.6 | 49.7 |
| Agriculture and vegetation | 277,797.6 | 223,967.5 | - 19.4 |
| Arid areas | 266,841 | 298,882.8 | 12 |
| Rocky areas | 1,214,912 | 1,214,912 | 0 |
| Total | 1,881,210 | 1,881,210 | 0 |

highlight how RV has affected the region's development but concepts such as proximity (collocate) and co-evolutionary (coevolve) still remain as an ambiguous point in these studies. In fact, the creation of economic synergy requires collocating and coevolving concurrently. Some researchers refer to the proximity as a factor to prevent co-evolutionary and mention the proximity paradox (imitation and pressure of competition as a factor in preventing innovation and new compositions) as an important factor in preventing the co-evolutionary of enterprises and clusters (Micek, 2019; Boschma, 2022; W. Liu et al., 2023).

Criticism raised for the RV in the world literature (Essletzbichler, 2015; Whittle & Kogler, 2020; Bathelt & Storper, 2023) is that in which fields among the industries the diversification is an important factor in creating more synergy. For example, the diversification in the field of technology, labor mobility or co-patenting (Fiorgo & Mayerhofer, 2018) profession, education (Wixe & Andersson, 2017), skill (Fitjar & Timmermans, 2017), norm, and institutional, cognitive, and social values among industries are referred to. To address these ambiguities, the study evaluated the size of industrial workshops, the number of subsidiaries of each industry, export orientation, co-evolutionary aspects, and proximity by thoroughly measuring the spatial linkages among the industries. The knowledge and technology spillover among industries were evaluated by measuring spatial linkages among the industries. The number of workshops and subsidiaries of any industry indicates its potential to create more synergy through innovation and recombination. In other words, the number of subsidiaries indicates the existence of ideas, creativity, and innovation in the field of human resources and the creation of new products. In addition, this reflects the dynamic of industrial evolution and the basis for the creation and expansion of new enterprises, clusters, and start-ups. On the other hand, this reflects the dynamic of industrial evolution and the basis for the creation and expansion of new enterprises, clusters, and start-ups. The formation of clusters in spatial form can also be attributed to the proximity and co-evolutionary of industries. The results of this study show that industries expanded by RV have played an effective role in creating economic synergy in TMR. In addition, it can be stated that the index of economic synergy measurement at the level inside the metropolitan area is the presence of industries growing in the RV in the form of spatial clusters. In fact, the existence of spatial clusters and their expansion respond to the ambiguity about imitation, competitive pressure, and institutional lock-in resulting from proximity and co-evolutionary as factors preventing synergy creation. Indeed, the backward and forward linkages between these clustered industries eliminate this ambiguity. Therefore, it is necessary to multiply the coefficient of RV and clustering coefficient to measure the RV and its role in economic expansion so that the extent the industries are influential could be determined by RV to create more synergy and economic expansion. The RV and clustering are recognized as an influential factor in this study to assess the economic synergy and its formula is presented as follows:

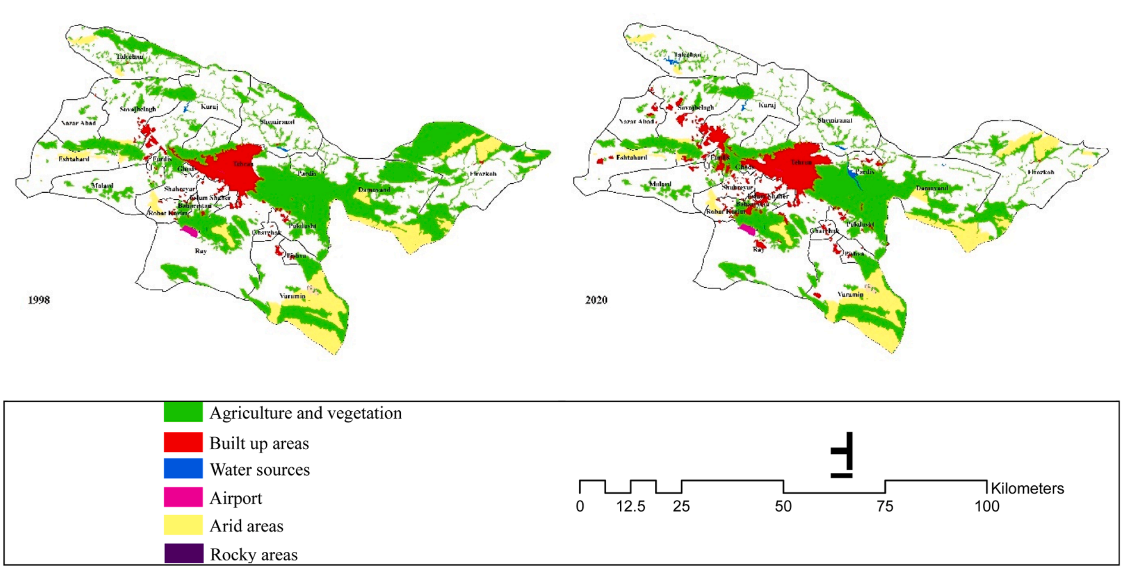


**Fig. 5.** Land use change trend from 1998 to 2020 in the TMR.

$$\text{Economic Synergy} = RV\left[\sum_{i=1}^{n}\left[K_{ij}+S_{ij}+F_{ij}\right].\,LQ.(DIBL_n\ .\ DIFL_n)\right].\,C_n \quad (20)$$

The study data were evaluated using EViews software to calculate this formula. RV and clustering variables were determined as independent variables and value added and direct and indirect employment coefficients as dependent variables. Table 8 evaluates the formula fit and shows that the significant level of the formula is desirable and the formula confirms 87 % of the effect of independent variables on the dependent ones.

However, the main challenge of TMR is unsustainability. The formation and expansion of industrial centers and industrial settlements in this region were not influenced by synergistic development principles. Certainly, the emergence of supply chains and value creation in the TMR has led to a significant displacement of goods, largely attributed to the gap in the evolutionary production cycle. The substantial increase in air pollution is directly linked to the inadequate development of transportation infrastructure and the concentrated land displacements. The main reason for this is the large number of cars and the consumption of gasoline and diesel hydrocarbon fuels. Notably, over 50 % of the pollution in this region stems from GHG emissions associated with transportation. Therefore, the expansion of green infrastructure can greatly contribute to the sustainability of the region.

Along with the industrial expansion in TMR, the level of unsustainability has also increased. In fact, sustainability indicators, especially in the environmental dimension, show that the TMR is not in a desirable situation. From a sustainability perspective, the spatial dispersion of industries shows that the expansion of industries has been towards the south and west of the TMR, and new spatial clusters have formed as a result of new externalities. Although laws and regulations such as the law banning the establishment of industries within 120 km of Tehran metropolitan region have led to a tendency towards spatial dispersion and divergence considering the metropolitan area's industrial activity, the significance of environmental regulations in influencing the spatial dispersion of industries is of secondary importance (Huang & Zhu, 2020). In fact, it can be stated that environmental regulations have led to the transfer of industrial pollution to the southern and western areas of the metropolitan region. Although the development of new technologies and strict regulations have somewhat reduced industrial pollution in large cities (Rubashkina, 2015; He et al., 2022), industrial activities still show a growth trend in TMR in terms of pollution. Studies of policies and regulations show that the main focus of these laws and regulations is on the location and establishment of workshops and industrial parks based on indices such as the production process, topography of the region, climatic conditions, environmental carrying capacity, dominant wind directions, urban and rural development directions, and prohibition of some industrial occupations and industries in cities. However, industries still play an important role in regional unsustainability. Furthermore, due to weaknesses in laws and regulations and their improper implementation, industrial development has expanded with little attention to environmental considerations, and economic growth has been accompanied by regional instability. The existence of fundamental weaknesses in the institutional structure, such as rentier government, and the existence of informational and economic rents as important factors in the location of industrial workshops, along with a centralized (top-down) planning system, have led to a non-dynamic institutional environment that has remained behind in desirable environmental policymaking. In fact, development issues, especially industrial development, in countries like Iran, due to the dominance of political economy, face various challenges that prevent the achievement of sustainable economic development. For example, policies that have led to the continuation of global economic and political sanctions have hindered the development of technology and the use of green technologies to reduce environmental pollution.

**Table 8**
Economic synergy measurement formula fit.

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| C | −0.553289 | 0.157349 | −3.516316 | 0.0005 |
| VR Coefficient | 0.629301 | 0.053187 | 11.83191 | 0.0000 |
| Clustering Coefficient | 0.377298 | 0.034957 | 10.79335 | 0.0000 |
| RES1(−1) | 0.268096 | 0.106037 | 2.528325 | 0.0117 |
| | Effects Specification | | | |
| Cross-section fixed (dummy variables) | | | | |
| | Weighted Statistics | | | |
| Root MSE | 0.106532 | R-squared | | 0.893092 |
| Mean dependent var | 0.508557 | Adjusted R-squared | | 0.879364 |
| S.D. dependent var | 0.422943 | S.E. of regression | | 0.113234 |
| Akaike info criterion | −1.773626 | Sum squared resid | | 9.385741 |
| Schwarz criterion | −1.231678 | Log likelihood | | 828.3944 |
| Hannan-Quinn criter | −1.565761 | F-statistic | | 65.05341 |
| Durbin-Watson stat | 1.862705 | Prob(F-statistic) | | 0.000000 |
| | Unweighted Statistics | | | |
| R-squared | 0.769218 | Mean dependent var | | 0.376102 |
| Sum squared resid | 9.385802 | Durbin-Watson stat | | 1.926436 |

Moreover, lack of attention to issues (e.g., green innovation, green transformation, using the technology innovation policies in environmental policies) leads to the regional unsustainability (Boschma & Frenken, 2018; Steen & Hansen, 2018; MacKinnon et al., 2019; Grant & Hicks, 2020). From the perspective of EEG, technological innovations and institutional transformation are aimed at creating green pathways and sustainable transfers in space to reduce pollution. This perspective, with an emphasis on carbon trading, environmental taxes, environmental governance, and pollution regulations, seeks to reduce negative environmental impacts (Boschma et al., 2017; Corradini, 2019). As a matter of fact, the displacement of affected industries by environmental laws and economic factors has not solved the problem of industrial sustainability. Therefore, focus on technological innovation to overcome technological lock-in and path dependency has been emphasized as an alternative solution to achieve a green and sustainable economy, instead of a complete transformation of the economic system from the perspective of EEG (Fraccascia et al., 2018; Schot & Kanger, 2018; Fastenrath & Braun, 2018). Ultimately, institutional evolution and technological innovations can lead to integration and synergy between the economy and the environment, resulting in regional sustainability. In this context, green technologies significantly reduce emissions and resource consumption and reduce climate change and environmental degradation. In this way, green technologies improve the quality of life by providing access to cleaner air and water.

The important challenges that metropolitan regions face is determining the types of industries to expand, the location of industries to achieve the greatest economic synergy, and at the same time minimizing environmental impacts. This study determines optimal locations for parks and industrial centers and identifies key industries. Synergy between the economy and the environment is enhanced by emphasizing environmental and economic indicators. Therefore, the findings of this study contribute to policymakers and planners in ensuring that industrial development in metropolitan regions aligns with synergistic indicators, and promotes the sustainability of these regions.

Finally, it can be stated that some factors are not properly recognizable in measuring the RV. For example, implicit knowledge spillover is one of the things that its disadvantages and benefits cannot be determined and evaluated clearly. It is also difficult to understand how it occurs at the regional level. On the other hand, the RV criticism, which utilizes the inter-regional potentials and capacities and does not use the extra-regional potentials desirably due to different structures, cannot be quantitatively evaluated. To address this criticism related to the contract assessment, an investigation into the connections between different areas is necessary. There is a fundamental problem for analysis in terms of data identicality and collection and this causes the scope of the research to become widespread. In the field between the economy and the environment, it seems that some changes are needed to be added to the synergy measurement formula. For example, the amount of energy consumption and the amount of pollutants and GHG emissions by industries should also be added to the formula to determine how much the economic and environmental benefits, in other words, cost-benefit analysis of industrial expansion is. In fact, the knowledge gap in the field of RV to its combination with environmental criteria and issues to respond to the challenges of unsustainability can be developed in a more effective way and be used as a role model for industrial expansion in the metropolitan regions of the world. However, increasing the efficiency of resources such as water, mobility, energy, and the use of materials makes societies more resilient, which reduces the cost of living. Economic sustainability protects the ecological system, and various aspects of environmental conditions are kept in balance.

This study focuses on the Tehran metropolitan region to validate and ensure the reliability of the indicators used. The field evidence was emphasized to demonstrate the correctness and accuracy of these indicators in measuring the research topic. One notable achievement is applying theoretical concepts as operational indicators to measure economic synergy at the regional level, which can be adapted for other metropolitan regions. Furthermore, achieving synergy between the economy and the environment is a key challenge for metropolitan regions. This study addressed strategies to respond to this challenge.

## 6. Conclusion

Achieving economic synergy among industries and reducing environmental damage caused by industrial expansion are among the current challenges in metropolitan areas. According to the results, TMR has been facing increasing growth and concentration in industrial workshops in recent decades. However, the TMR has experienced increasing environmental problems at the same time. The policies used for industrial expansion have only led to spatial dispersion and the creation of industrial workshops, and concepts such as synergy have received less attention in the creation of workshops and industrial locations. At the same time, policymaking to reduce environmental problems, especially in the industrial field, has not been able to reduce these damages. Thus, the primary objective of this research is to promote regional sustainability by fostering synergy between the economy and the environment. Global studies (e.g., Sharifi, 2021; Tavera Romero et al., 2021) indicate that the RV concept, as a criterion to measure economic synergy, has faced criticisms, and an attempt was made in this research to use this index to measure the economic synergy between industries by modifying it. Through modifications to the RV formula and the incorporation of clustering analysis, this index gains enhanced utility to measure economic synergy among industries. Out of the 28 different types of industries in the metropolitan region, only 10 have the potential to develop synergy, according to the results of the RV analysis and industry clustering. In addition, the investigation of the environmental situation showed that only economic factors played a role in locating and expanding these industries, and environmental policy-making played a passive role. Two challenges can be seen in metropolitan regions in terms of industrial development. The first challenge is occurring rapid industrial growth in some areas without considering the balance between economic needs and environmental impacts. Thus, insufficient industrial development and increasing destruction of the environment have occurred. Second, emerging key industries in the regions have two challenges: choosing the types of industries to promote and the location of these industries. This research provides valuable insights into industrial siting locations and optimal strategies to increase synergies while minimizing environmental problems. Furthermore, planners and policymakers can make sustainable development decisions in metropolitan regions with a clear framework.

Measuring the indices such as industrial pollution, GHG emissions, and energy consumption indicate the unstable situation of TMR. However, the existence of environmental regulations and policies in the field of location and industrial activities has focused mostly on the transfer of industries from the environments close to the cities to the peripheral areas and has not caused the reduction of environmental damages. Consequently, TMR is facing unsustainability. Therefore, instituting evolutionary changes and transformations in policy-making for the expansion of industrial activities is crucial to overcome the sustainability challenge in this region. Furthermore, the expansion of technologies, innovations, and green infrastructure will make a substantial contribution to lowering this region's unsustainability. In this regard, policy implications for promoting sustainable development, i.e., improving the economic and environmental performance of industries in the TMR, can be in reducing costs. Sustainable practices can lead to reduced energy consumption, reduced waste disposal costs and more efficient use of resources, resulting in significant cost savings. In addition, this practice brought increased revenue through the entry of new customers and the creation of markets in pursuit of sustainability. In the context of sustainable development, human activities emphasize the resilience of purely natural systems and push them to the point of failure, affecting all aspects of the environment, not just climate.

### *6.1. Policy recommendations*

The experience of the TMR indicated that not paying attention to the indices of economic synergy in locating and expanding workshops and industrial settlements has also caused environmental problems in addition to reducing economic productivity. For example, increasing the geographical distance between the supply and value chains within them has caused an increase in the cost of transportation and an increase in environmental pollution. Hence, this study makes suggestions to policymakers and researchers in two sections. Firstly, the extent of economic synergy and environmental sustainability of industries can be evaluated concurrently by adding criteria such as energy consumption, contribution to pollution, and GHG emissions to the extracted formula to measure the economic synergy and this will greatly help locate the industrial workshops based on environmental and economic considerations. Secondly, we need to review industrial policies in the field of industrial expansion. It is recommended that the countries seeking to expand industries pay attention to concepts such as complementarity and synergy in the creation of industries and pay due attention to the environmental considerations that are specific to each place concurrently. In fact, policy-making industriy should be based on the framework of environmental and economic synergy to locate and expand industries.

## CRediT authorship contribution statement

**Saeid Zarghami:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Anwar Eziz:** Conceptualization, Methodology, Validation, Writing – review & editing. **Narges Siamian:** Conceptualization, Methodology, Validation, Writing – review & editing. **Ivana Janeska Stamenkovska:** Conceptualization, Methodology, Validation, Writing – review & editing. **Laima Skauronė:** Conceptualization, Methodology, Validation, Writing – review & editing. **Hossein Azadi:** Writing – review & editing, Validation, Methodology, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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