International Journal of Hospital Research 2018, 7 (4)
http://ijhr.iums.ac.ir
Research Article

Dynamic Analysis of Environmental Factors Affecting Health Costs Applying a System Approach (Case Study: Zanjan City, Iran)

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Abstract
Background and objective: Today, due to the growth of technology in various societies and in line with the industrialization of the global community, environmental issues are becoming a serious threat to human health and consequently, to the economy of the international community. The city of Zanjan, as a case study of this research, has been witnessing various civil protests in this regard and over the past years due to environmental concerns.
Methodology: System Dynamics (SD) methodology is applied to simulate the dynamics of environmental pollutions of the various industries affecting health costs. Dealing with SD, study has been applying content analysis technique to select the most repetitive variables applied with similar studies which led study to the early mental model (causal loop diagram). Interview with experts is the next step which would assist the study to make the early dynamic model. The modified dynamic model has been grasped as the structural validation is conducted within 4 divisions of boundary adequacy test, extreme condition test, dimensional consistency test and parameter assessment test. Finally, the secondary validation including: behavior replication test and family tests have been assessed to assure the compliance of model outputs with the historical records.
Results: According to the simulation, the most prior recommendations are: "Long-term policies for less utilization of non-renewable resources", "Increasing the life of industrial capital through the promotion of maintenance and repair departments", "Replacing fossil fuels with natural gases and enhancing their combustion quality" and "desertification policies to combat the release of solid PM10 particles".
Conclusions: Based on the results of the study, long term policies to find out the appropriate tradeoff for exploitation of renewable and nonrenewable energies in order to minimize their pollution will have a bigger effect on the citizen's health costs comparing other policies like desertification.
Key words: Pollutant, Environmental, Health cost, System Dynamic

Background and objectives

Aligned with technological advances in different communities and the industrialization of the world community, environmental problems are turning into a serious challenge threatening human health and the economy of the world community. This is because, the environmental pollutants trigger increase in different diseases and consequently, increase in health costs in different communities that subsequently, causes an increase in the use of financial resources of health sector supplied from national income[1]. It should be noted that increased environmental pollutions impose staggering costs to economy through increasing diseases and leads to disease-related work leave in the industries of different communities due to the increase in airborne particles[2]. Relying on[2]

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findings, it can be argued that increased air pollution leads to reduced productivity and production as well. Although health-related costs impose a heavy burden on such communities, these consequences can result in economic growth via creating demand for improved health indices of economy. In other words, on the one hand environmental pollution-induced problems are considered as a threat for communities and eco-system health and on the other hand can result in economic flourish via promoting the health indices of economy. Hence, nowadays governments have discovered the importance of this matter and formulated different policies, rules and regulations in this sector in order to adjust environmental pollutions[3].

This study evaluates Zanjan city as case study since its environmental concerns as the main source of lead and zinc mines in Iran, justifies this study. It should be mentioned that Zanjan has experienced different civil protests in recent years due to the environmental concerns. The staggering increase in digestive and pulmonary diseases and consequently the staggering increase in the health costs of households have raised public dissatisfaction and harmed the socio-economic texture of this city over recent years and decades[4]. Therefore, the evaluation of such pollutants, caused by lead and zinc, and their influencing mechanism on Zanjan economy, as one of the biggest cities of the northwest of Iran, can be attractive for both regional and trans regional (national) policy-makers. This is because in regional level, environmental challenges are significantly important in terms of biological, social, health and consequent economic issues due to aforementioned reasons. Moreover, in national level, this study can be attractive due to the similarity of Zanjan with other cities, especially high-polluted cities suffering industrial and non-industrial pollutants. Based on above discussions, the objectives of this study is to find the appropriate range of industrial, service and agricultural variables for macro policy-makers of these sectors based on environmental pollutions and with the aim of reducing health costs in both regional (Zanjan) and trans regional (national) levels.

Background of the study

The main portion of studies on this field can be divided into two general categories. The first one encapsulates studies evaluating the relationship between environment, health and economic growth while the second one covers studies evaluating the effect of special type/types of pollutants on the health indices of a particular region applying case study approach. This study first reviews the literature of the first category in both international (foreign studies) and national (domestic studies) levels and then, reviews the literature of the second category in order to evaluate the quantitative effects of the most important environmental pollutants in international (the world), national (Iran) and regional (Zanjan) levels.

Health, environment and economy

Health of individuals which is dependent on a set of behavioral and non-behavioral (environmental) variables is a part of the human capital. Therefore, it affects the process of economic growth in organizations in which the individual work. On this basis, some researchers consider the *health* in economic growth models and patterns as a component of human capital[5]. Madadi is the first researcher who explained the concept of health capital. He believes that the health status of individuals is a type of capital and considers health as a capital good producing a healthy life as final product for mankind[5].

Madadi believed that it is possible to introduce health variable into the human utility function. In other words, health capital explains how much time each of us spends to earn money[5]. According to Madadi research, the relationship between economic growth and health costs can be studied by two methodologies, similar to the majority of economic issues. The first one is the analysis of the influencing mechanism of health variables on national economic models and the second one is to quantitatively estimate change rate and to identify mechanisms which transfer changes among variables[5].

Mediated by industrial revolution, environmental pollutions have accompanied with harms, the footprint of which could be sought in the health sector. As consequence of the acceleration of industrial and technological development, environment has not been the area of focus for long years. On the one hand, the development of countries necessitated further extraction of natural resources and on the other hand, industrial activities produced numerous pollutants and wastes s well[6]. It might have been supposed for a long time that nature is an endless resource for extraction and is a suitable place to be used to clean pollutions induced by industrial productions and activities. Passing time, it was proved that natural resources will be ended and the accumulation of pollutions in nature will harm both nature and human[6]. At the following Table 1, some studies on this area are explained.

Table1. Studies on health and environment economy

Author	Results
Alizadeh et al[6]	Results showed that despite formulating various policies in the five-year development plans of Iran, there is no change to the compliance of Iranian energy policies with the targets of Kyoto Protocol.
Knowles, & Owen[7]	They added health capital to Solo's growth model and showed the strong relationship between health capital (as a capital caused by environmental factors) and income.
Hansen & Selte[8]	They studied air pollution and its impacts on people's health. Concentrating on the data of Oslo citizens in Norway within a Logit model. They showed that increased particulate matter leads to increased work leave due to diseases.
Jerrett et al[9]	They found that sectors with more investments associated with improving the quality of environment, bear the lower treatment costs.
Hadian et al[10]	They evaluated the effect of changes in health costs on Iran economic development. Their results indicated that increased health costs have a significant positive effect on economic growth. They believe that in addition to the direct effects, increased health costs will go with indirect effect too and can promote the development of production in economy through reducing in mortality and work leave.
Hadian et al[10]	They argued that, historically, environment has been a target for the policies of health sector across the world. According to them, the relationship between environment and health is more evident in developing countries where the continuous entrance of toxic and pollutants to the environment has highlighted the negative effect of environment destruction on health sector.
Yoo et al[11]	They provided a different approach to measuring air pollution-induced health costs in Seoul. Their results demonstrated that Seoul residents

Author	Results
	are ready to pay 170 million dollars monthly in order to reduce pollutions in Seoul by 10%.
Zhang et al[12]	They concentrated their study on the impacts of PM10 emissions. Their results showed that this pollutant imposes more than 29178 million dollars health cost to the society.
Lee& Wang[13]	Their results indicated that cost-benefit ratios are 1:5 and 2:15 in power plant and industry sectors respectively (in case of adopting more productive clean energy policies). Therefore, they concluded that due to significant positive effects on the promotion of public health, air pollution reduction policies will be economically justifiable.
Coury & Hartwell[14]	In a comprehensive study, they studied the relationship between economic, environmental and health indices using nearly 20 indicators across 130 countries. Their results indicated that although increased income and enhanced education level are along with increased utilization of natural resources, exploiting natural resources becomes more optimized and emissions are reduced due to adopting better technologies and promoting different available technologies.
Ansari & Seifi[15]	They conducted a study to analyze energy consumption and carbon dioxide emission in Iran Cement Industry under different scenarios. This model includes the demand for cement, energy consumption rate and carbon dioxide emission in an integrated structure emphasizing on the use of natural gases (NG). Their results showed that removing subsidies of energy can potentially reduce the consumption of natural gases (NG), electricity and carbon dioxide emissions by 29%, 21% and 22%, respectively.
Drabo[16]	Drabo indicated that how the destruction of environment due to income inequality (exploiting more natural resources for earning purposes) can aggravate and decline health indices. In Drabo's econometrics model, income inequality has a negative effect on health indices. However, when environmental pollutants (Sulfur, carbon oxides and water pollution indices) are added to the model as additional variables, this alters the significance of this effect.

Review of case studies on environmental pollutants

The final part of literature, reviews the most important case studies conducted on environmental pollutants in international, national and regional levels. According to Table 2, previous studies have evaluated the most important pollutants in different and unequal ranges over different levels. International studies have evaluated soil, water and air almost equally while within national studies, this balance cannot be seen and air pollutants are taken into account in most cases. Meanwhile, regional studies have less concentrated on air pollutants comparing national level. These studies have taken lead and zinc-induced pollutants into account due to the existing sensitivity of Zanjan citizens.

Table2. Studies on environmental pollutants in international (foreign), national (Iran) and regional (Zanjan) levels

Level	Particles	Areas (categories)	Countries (cities) of studies
International[17-23]	Solid particles (PM2.5, PM10)	Soil, air (arid lands, transportation system)	Chine (Beijing), China (Shanghai), India (New Delhi), India (Patna), Pakistan (Karachi), Pakistan (Peshawar), Iraq (Baghdad), Indonesia (Jakarta), Malaysia (Johor), Malaysia (Kuala Lumpur), America (New York) and Europe Union
	No2	Air (transportation system)	
	SO2	Air (production industries)	
	Volatile organic compounds (VOC)	Air (production industries)	
	NH3	Soil (cultivable lands in agricultural sector)	
	Pb (lead)	Water (production industries)	
National[24-28]	Solid particles (PM2.5, PM10)	Soil, air (arid lands, transportation system)	Iran (Tehran), Iran (Zabol), Iran (Ahvaz), Iran (Khorramabad), Iran (Tabriz), Iran (Isfahan), Iran (Mashhad),Iran (Shiraz) and Iran (Zanjan)
	NO2	Air (transportation system)	
	SO2	Air (production industries)	
	Volatile organic compounds (VOC)	Air (production industries)	
	CO	Air (production industries-transportation system)	
	Total hydro carbons (THC)	Air (production industries-transportation system)	
	Ozone (O3) of the earth surface	Air (transportation system)	
Regional[29-34]	Pb (lead)	Water and soil (production industries)	Zanjan (across Zanjan), Zanjan (30Km off industrial zinc town), Zanjan (Angooran), Zanjan (lead and zinc industrial zone)
	NO3 (Nitrate)	Water (production industries)	
	CO (carbon monoxide)	Air (production industries)	
	Cd (cadmium)	Water and soil (production industries)	
	Cr (chrome)	Water and soil (production industries)	
	Zn (zinc)	Water and soil (production industries)	
	CU (copper)	Water and soil (production industries)	
	Ni (Nickel)	Water and soil (production industries)	

Method

Two classic modeling methodologies are widely applied to study energy and environmental policies of future energy and economy. Both methodologies i.e. macroeconomics (up to down) and technological techniques (down to up) have their own advantages and disadvantages[35]. Down to up models advantages are providing energy-related technologies within partial equations. In addition, they can assess the trends and financial costs of different technological choices. These are considered as the advantages of these models. On the other side, they cannot measure the macroeconomic impacts of energy policies and this is the disadvantage of these models. On the contrary, up to down models include computational general equations (CGE) that have been widely used to demonstrate the interactions of economic enterprises. Up to down models can calculate costs in macroeconomic level and can determine the impacts of energy policies both in considered enterprises and in the technologies used by studies[5].

System analysis is the third methodology which includes System Dynamics (SD) as a renowned method in this area. SD is a robust modeling methodology used to understanding and evaluating the mechanisms of complex systems. SD models are well-known to analyze energy policies including environmental issues and are applied as a model having capability of establishing relationships among tangible structures of systems and the detailed level of them that consequently can facilitate decision-making process. SD has been widely used in the demand-supply analysis in Iran oil and gas industries[15].

The methodology of SD is based on the fact that the sophisticated behaviors available in social and organizational systems are the product of the accumulation of people, materials, information, financial assets and even mental and biological status in both reinforcing and balancing mechanisms[36]. Lee believes that some concepts like *accumulation* and *feedback* are not new concepts since they have been discussed in different forms in previous centuries[37]. According to research of Forrester and Wheat, SD provides the practical applications of these concepts in the form of mathematical models with the ability of providing replacement policies and scenarios aligned with examining systems for answering both "if, then" and "why" questions[38, 39].

Regarding the diversity of pollutants and their origins, this study applies the third methodology of SD to dynamically evaluate the environmental emissions of different industries affecting health costs in Zanjan city. The majority of previous studies have evaluated pollutants only by focusing on a single type of pollutants. This is why they have adopted regression and panel data models as none of them have had a system view towards the evaluation of relationships among variables. Thus, this study adopted System Dynamics (SD) methodology for three following reasons: 1) this study includes several variables (more than two variables), 2) there are non-linear relationships between study variables and 3) this study aims to implement a system approach. The applied software to conduct simulation is Vensim PLE x32 as well.

The study procedure has been indicated at the following flowchart (Figure1). The study starts with a robust literature based on previous studies background. Then study goes on applying a *content analysis* to select the most repetitive variables applied with similar studies. *Content analysis* is a research technique used to make replicable and valid inferences by interpreting and coding textual material[40]. This technique helps the study to build a logic boundary for model within logic numbers of variables. It differentiates between the most and least replicable variables. Hence, this technique leads the study to the early mental model or causal loop diagram. Interview with experts is the next step which would assist the study to make the early dynamic model. Units, type (constant, auxiliary or Lookup), formula and Lookup values of variables and correlations among them are the titles of interview to be conducted with experts. Adaptation of these titles with experts and secondary data (literature review) are essential sub-steps to make early dynamic model.

The modified dynamic model will be made as the structural validation is conducted within 4 divisions of *boundary adequacy* test, *extreme condition* test, *dimensional consistency* test and *parameter assessment* test. These tests will be applied in the discussion division. Finishing the mentioned tests, would kindly build a modified model in which no error the software shows. Afterward, the secondary validation including: *behavior replication* and *family member* tests will be assessed to assure the compliance of model output results with the historical records. The study will enter the next step of scenario proposals based on the proposed objectives of study. The modified model will be run to carry out simulations according to scenarios. Finally outputs of simulation based results will be analyzed and deducted at conclusion part which includes recommendations of study to improve the current circumstances.

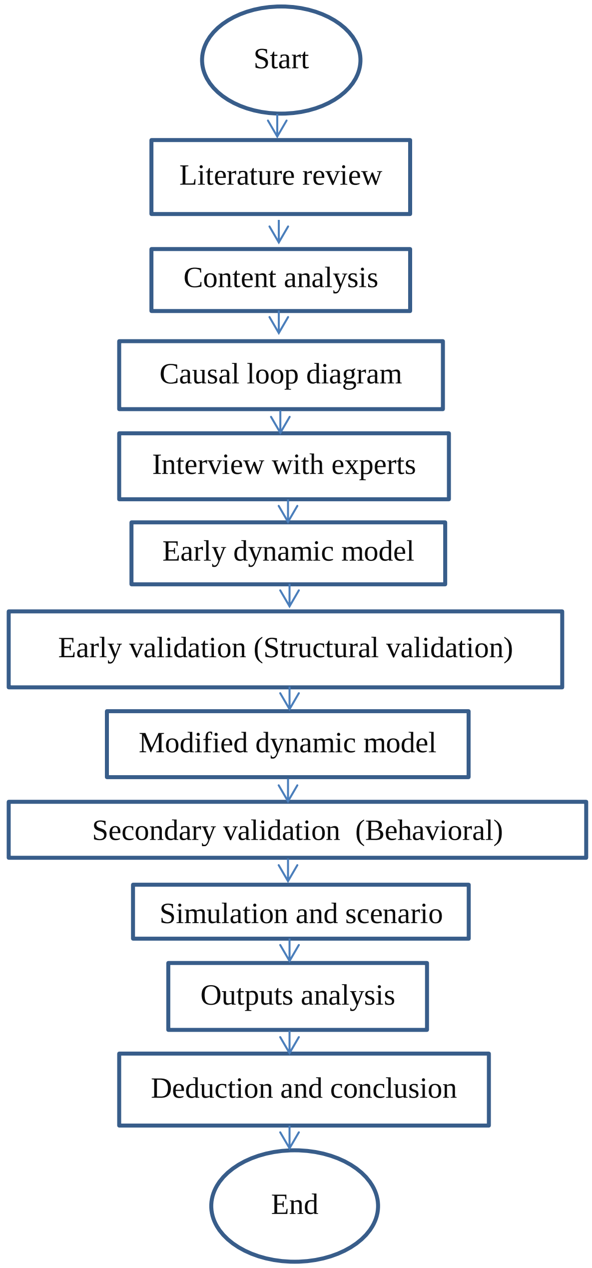

Fig1. The procedure of research methodology

Discussion

In this section the study carries on within three sub-sections of *causal loop diagram, stock and flow diagram* and *scenario planning and results*. Casual loop diagrams aim to determine the relationships between variables, stock and flow diagram will indicate the central part of the model (pollution mass) and finally at the scenario planning part, the study will submit the required scenario to meet the study objectives requirements by generating corresponding results.

Causal loop diagram

As it was discussed before, casual loop diagrams aim to determine the relationships (direct or indirect) between variables (constant, auxiliary and level variables) and to define feedback loops (reinforcing or balancing) in simulations. Fig. 2 shows the casual loop diagram of this study. Determining relationships between variables and consequently forming feedback loops, this diagram aims to provide a system explanation of the correlations between the influential factors of environmental pollutants originated from different industrial, service and agricultural sectors. The boundary of this diagram which defines the boundary of the studied model has been determined based on *content analysis*. In the conducted *content analysis*, all influential factors effecting health environmental-based costs are enlisted within a checklist considering previous studies and factors where the highest replications are selected for the studied casual loop diagram and model. In this casual loop diagram, the influential factors effecting environmental pollutants (having impact on health costs) are assessed in the industry (sector 1), service (sector 2) and agriculture (sector 3) sectors. Subsequently, the correlations among variables are demonstrated by the tip of arrows (direct or indirect relationship). This diagram has various feedback loops and at this section, the study evaluates the most important loops explaining the above mentioned three sectors. Table 3 shows the variables constituting the main loops of the studied model.

Table3. The main loops of the casual loop diagram of the studied model

Item	Loop 1 (service) Reinforcing loop	Loop 2 (industry) Reinforcing loop	Loop 3 (agriculture) Reinforcing loop	Loop 4 (agriculture) Balancing loop
1	Pollution mass – Service sector	Pollution mass – Industry sector	Pollution mass – Agricultural sector	Arable lands
2	Pollution mass generation rate	Pollution mass generation rate	Pollution mass generation rate	Food ratio
3	Environmental based health costs per capita	Environmental based health costs per capita	Environmental based health costs per capita	Fraction of agriculture input for land development
4	Life expectancy	Life expectancy	Life expectancy	Arable land developing rate
5	Fertility	Fertility	Fertility	Development cost per hectare
6	Birth rate	Birth rate	Birth rate	Non arable land
7	Population < 40	Population < 40	Population < 40	Developing cost per hectare
8	Population	Population	Population	Land development productivity
9	Industrial output per capita	Urban & industrial lands needed	Urban & industrial lands needed	Land yield
10	Fraction of service	Arable lands	Arable lands	Average land life

Item	Loop 1 (service) Reinforcing loop	Loop 2 (industry) Reinforcing loop	Loop 3 (agriculture) Reinforcing loop	Loop 4 (agriculture) Balancing loop
	inputs	destruction	destruction	
11	Service - investment	Arable lands	Arable lands	Land erosion rate
12	Service capital	Food ratio	Pollution mass generation rate - agricultural sector	Arable lands
13	Service output	Fraction of agriculture input for land development	-	
14	Service output per capita	Fraction of industrial output allocated to agriculture	-	-
15	per capita resource use	Industrial sector inputs	-	-
16	Pollution mass service	Industrial – investment	-	-
17	-	Industrial capital	-	-
18	-	Industrial output	-	-
19	-	Industrial output per capita	-	-
20	-	per capita resource use	-	-
21	-	Pollution mass – Industry sector	-	-

According to the indicated loops at the above Table3, three of four loops are *reinforcing* and only the last one (Arable land – agricultural sector) is a *balancing loop*. A *balancing loop* attempts to move some current state (the way things are) to a desired state (goal or objective) though some action (whatever is done to reach the goal), while a *reinforcing loop* is one in which an action produces a result which influences more of the same action thus resulting in growth or decline.

As it is indicated at the causal loop diagram, there are many balancing loops and some of them need to be clarified. These loops are those which have been highlighted by *desired and current statuses*. The differences between these two statuses make a gap which needs to be filled out. These gaps have been illustrated within the causal loop diagram different sectors of *fertility*, *industrial output*, *service output* and *food ratio*.

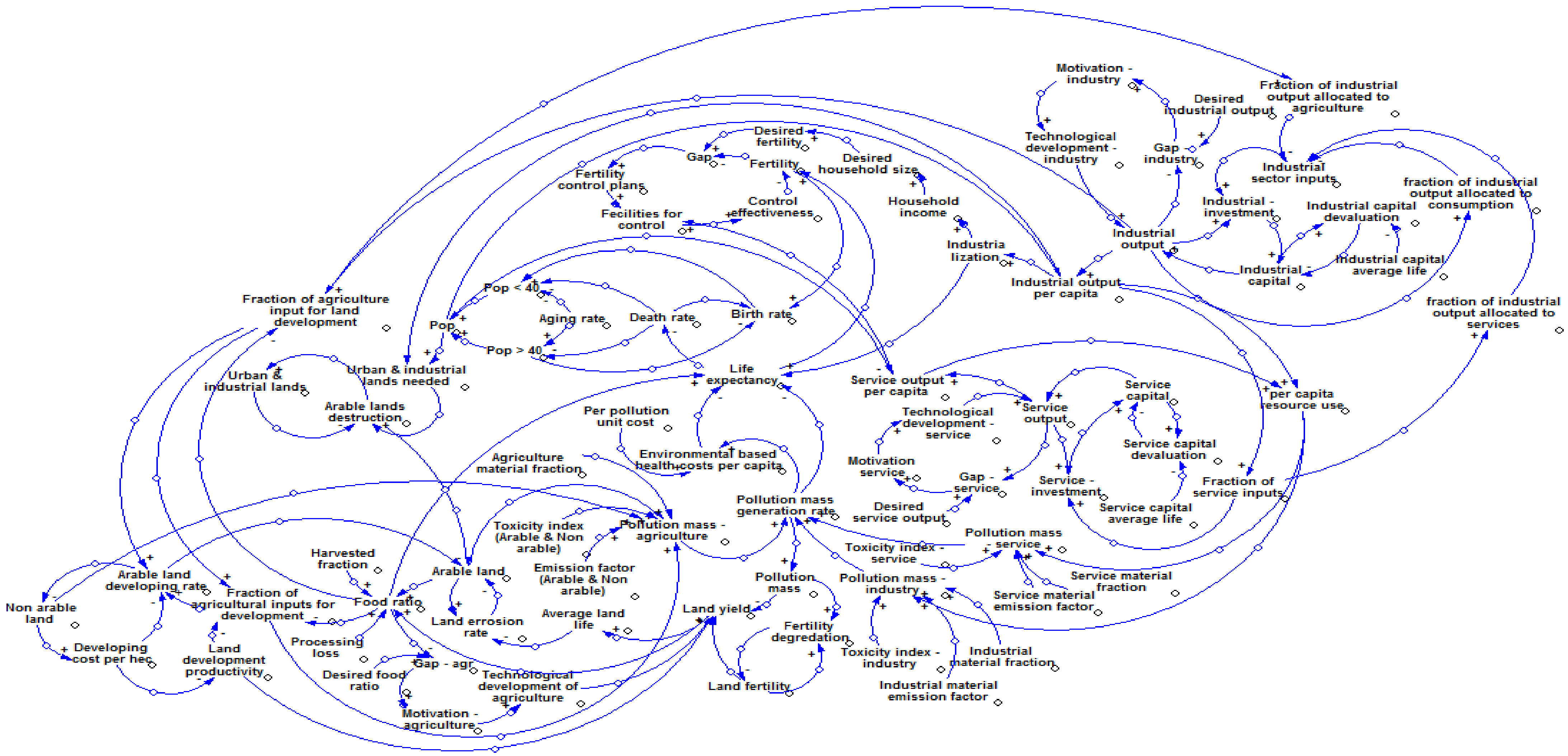

Fig2. Casual loop diagram of the studied model

Regarding same reasoning, the different sectors of applied case study (Zanjan) have different behaviors based on the simulation. At the *service output* sector, generated pollution derived from this sector has an exponential behavior toward growth (Loop1 – reinforcing loop). Same behavior is indicated by *industrial output* sector where there is no balancing element within this sector to adjust the *pollution mass* and its pollution is exponentially growing as well (Loop 2 – reinforcing loop). On the other hand, there are two sub-sectors in the agricultural sector including *arable and non-arable lands*. The ongoing pollution derived from non-arable land (PM10) will be reinforced within a reinforcing loop implying a need to consider preventive and controlling measures (Loop 3, reinforcing loop). On the contrary, *arable lands* do not have same status and its pollution (Ammonia) is going to be balanced over a balancing loop (Loop 4).

Stock and flow diagram

The casual loop diagram of the studied model was analyzed at previous section. The different parts of the model were evaluated within a system approach and the feedback loops resulted from correlations among these parts and subsets variables were investigated as well. One of the weaknesses of casual loop diagrams is their disability to indicate constant variables since these variables are exogenous and are not affected by other variables. Hence, the most important constant variables are explained over the central part of the current model (pollution mass):

- **Emission Factor (EF)**: According to Chen *research emission factor* is the average emission rate of type/ types of greenhouse gases emitted from type/ types of obtained resources; whereas, the emission mass is depended on the utilization fraction of these resources[41]. *Emission factor* values of study were obtained from the researches of Liu et al and Chau et al which have applied different *emission factors* for different materials in their own studies[18,42]. To clarify this factor, it has been submitted as follow where P, R, 10 and C are the percentage of the studied substance in fuel, residual amount of the studied after combustion, conversion factor and net calorie of the fuel per ton respectively.

$$EF = \frac{p \times (1 - R) \times 10}{C}$$

- **Toxicity Index (TI)**: According to Lioy research, *toxicity index* is the number of toxic substances released from a particular type of material divided by the total volume of the material within its consumption form. Regarding material various forms, *toxicity index* is explained in various forms as well. These forms include oral, skin, gas, vapor and dust. *Toxicity index* is formulated as follows where C and STEL are *concentration of fuel vapor over fuel surface* and *standard emission level of fuel* respectively[43].

$$TI = \frac{C_i}{STEL}$$

- **Health cost per capita per pollution unit**: According to the previous studies, there is a correlation between public health costs and environmental pollutions. The value of this correlation called as *correlation coefficient* is 0.000845 in MENA countries which includes Iran[19]. The unit of this variable is $/(Pollution unit*Person) as well.

- **Pollution transferring delay**: *Pollution transferring delay* is the average time between the entrance of pollutants emitted from industrial, service and agricultural resources to urban areas and the time when their effects on the areas become measurable. To meet modeling requirements, the study has applied function of *delay*.
- **Pollution absorption time in 2018**: According to research of Fujii, *pollution absorption time* is the rate of the absorption caused by plant coverage (vegetation) and the atmosphere. Meanwhile, the half-life of environmental pollutants is called *absorption time* in this study since the year 2018 (the closest year with published data to 2020)is the mid-point of simulation period (1990-2050)[44]. The absorption rate is estimated using equation 3, considering the vegetation and topographic features of the Zanjan city. This equation can be applied for any type of pollutant while it was used in Fujii study only for CO_2. In this equation, c_0, c, q, t, v and s stand for pollutants concentration of outdoor air, pollutants concentration in the chamber, ventilation rate, the study time, vegetation area and the surface area of leaf respectively. It should be noted that the vegetation of the Zanjan city was estimated using secondary data and online aerial photos.

$$\alpha = \frac{C_o q\Delta t - C_{(t)} q\Delta t - V\{C_{(t)} - C_{(t-\Delta t)}\}}{C_{(t)} s\Delta t} \qquad (3)$$

- **Industrial capitals half-life**: In this study, the *industrial capitals half-life* refers to the average life of technologies (facilities and equipment) in the industry sector. According to research of Weisz et al, the life of these capitals ranges from 1 to 50 years before being scraped. This study used the average value of this range[45].
- **Service capital half-life**: in this study, *Service capital half-life* refers to the average life of technologies (facilities and equipment) in service sector. According to research of Pauliuk et al, the life of these capitals ranges from 1 to 40 years before being scraped. This study considered the average value of this range[46].
- **Agricultural capitals half-life**: In this study, *Agricultural capitals half-life* refers to the average life of technologies (facilities and equipment) in agriculture sector. According to research Pauliuk et al, the life of these capitals ranges from 1 to 40 years before being scraped. This study considered the average value of this range[46].

- The rest of this section evaluates the main part of the model (pollution mass). According to Figure 3, *pollution mass* as a stock (level) variable has an input (pollution generation rate) and an output (pollution absorption rate) which increases and decreases *pollution mass* respectively. At the part of *pollution generation rate*, study discusses the production mass generated by industry, service, agriculture (arable and non-arable lands) and technological sectors. *Pollution absorption rate* will be discussed in its section as well:
- **Pollution generation rate (industry, service and agriculture)**: Relying on the secondary data (previous studies and annual statistics), this section considered lead, zinc and natural gas (hydrocarbons) as the main pollutants of industry sector, gasoline as the main pollutant of service sector (public transportation), particulate matter (PM10) as the main pollutant of agriculture sector (non-arable lands) and ammoniac as the main pollutant of agriculture sector

(arable and fertilized lands) in Zanjan city. All the mentioned pollutants are coordinated as (A, B, C) in Table 4 to develop scenarios of study. The components of this coordination are *emission factor* (A), *toxicity index* (B) and *the fraction of resources from pollution materials* (C) respectively.

- **Pollution generation rate (technological division)**: This factor is associated with motivating factors. The society struggles to improve or adjust the technological factors depending on the existing gap between current technological statues and the desired one.
- Thus, it should be considered since this factor can have impact on environmental *pollution mass*.
- **Pollution absorption rate**: *Pollution absorption rate* means the rate of the environmental pollutions absorption to nonurban and industrial areas.

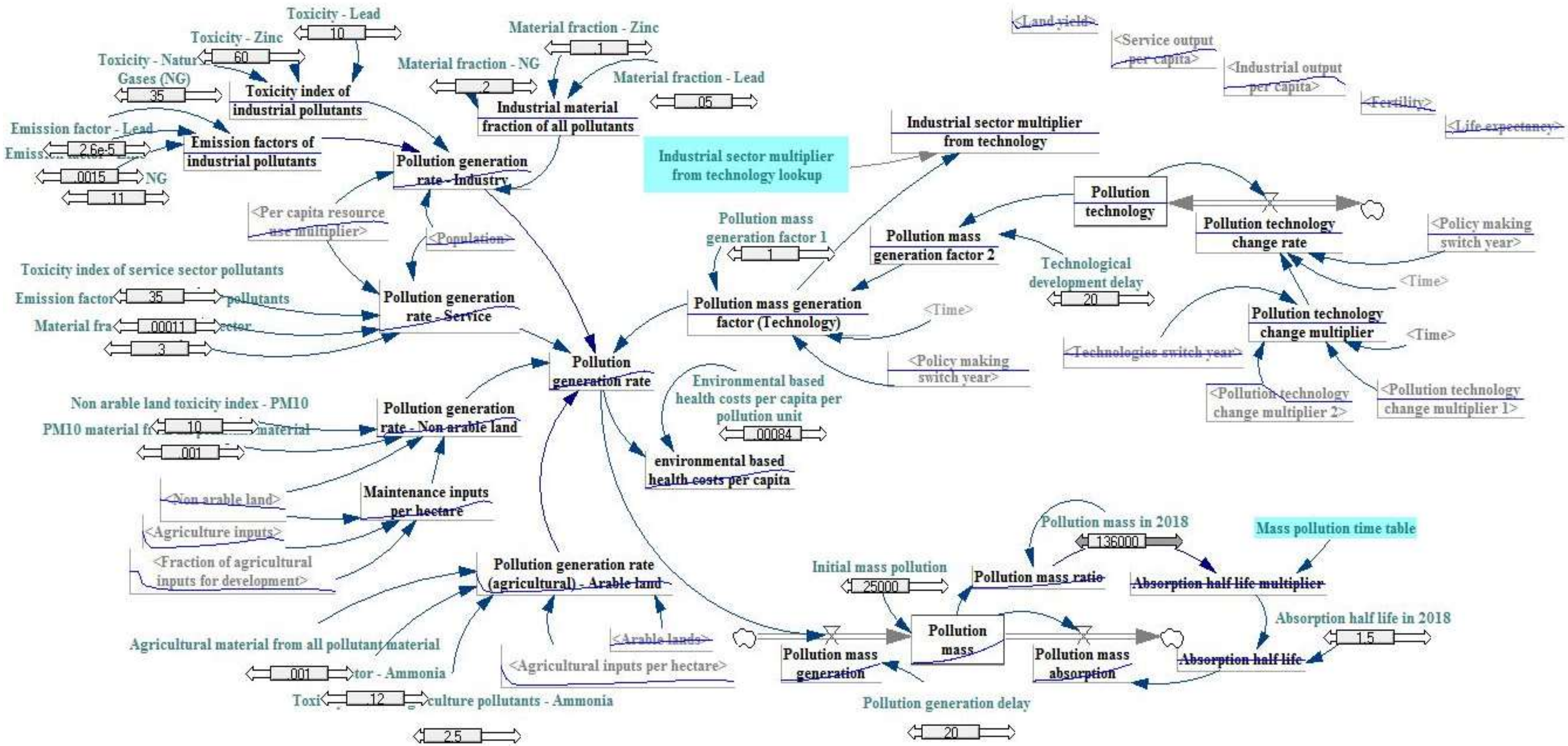

Fig3. Central part of the model (Pollution mass) – Run status

Table 4. Study scenarios (changes made to create new scenarios are highlighted by yellow) – to be continued

Sector	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10
Industry	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60,0.1)	Lead (1.3E-004, ١٠, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, ۵٠, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.1) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.55,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,175,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.4) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0075, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 300, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.2)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)
Service	Gasoline (0.00011, 35,0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00055, 35, 0..3)
Agriculture	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)
Non arable lands	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)
Industrial capitals life	15 Year	15 Year	15 Year	15 Year	15 Year	15 Year	15 Year	15 Year	15 Year	15 Year	15 Year
Service capitals life	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year
Agricultural capitals life	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year
Pollution absorption	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year
Health cost per pollution unit	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845
Utilizing non-renewable resources	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008

Table 4. Study scenarios (changes made to create new scenarios are highlighted by yellow) – The second part

Scenario 11	Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18	Scenario19	Scenario 20	Scenario 21	Scenario 22
Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60,0.1)	Lead (1.3E-004, ۱۰, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, ۵۰, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.1) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.55,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,175,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.4) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0075, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 300, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.2)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)	Lead (2.6E-005, 10, 0.05) NG (0.11,35,0.2) Zinc (0.0015, 60, 0.1)
Gasoline (0.00011, 175, 0..3)	Gasoline (0.00011, 35, 0..6)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00011, 35, 0..3)	Gasoline (0.00055, 35, 0..3)	Gasoline (0.00055, 35, 0..3)
Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 12.5, 0.001)	Ammoniac (0.12, 2.5, 0.002)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)	Ammoniac (0.12, 2.5, 0.001)
PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 50, 0.001)	PM 10 (0, 10, 0.002)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)	PM 10 (0, 10, 0.001)
15 Year	15 Year	15 Year	15 Year	15 Year	15 Year	60 Year	15 Year	15 Year	15 Year	15 Year	15 Year
20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	20 Year	80 Year	20 Year	20 Year	20 Year	20 Year
25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	25 Year	10 Year	25 Year	25 Year	25 Year
1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	1.5 Year	20 Year	1.5 Year	1.5 Year
0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000845	0.000085	0.000845
1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1.2E+008	1E+007

Results

Prior to running this model and obtaining outputs, the assumptions of this model are described as follows:

- Simulations were conducted for a period of 60 years (1990 - 2050), since a dynamic simulation requires half-life values and this is why that the year 2018 (the closest year with published data to 2020) should be selected as mid-point of simulations periods. Simulations were conducted using Vensim PLE x32 with time step equal with 0.5 where time unit was considered to be *year*.
- The values of multipliers used in the model (lookup variables) were defined and introduced to the model based on P-value and F-value derived from regression and logarithmic techniques used in previous studies.
- In the *Pollution mass* sector, according to the assumption of the study, pollution is derived from *Technological factor* aligned with *Service*, *Industry* and *Agriculture* as well. It is notable that *transportation* is the sub-sector of *service* sector

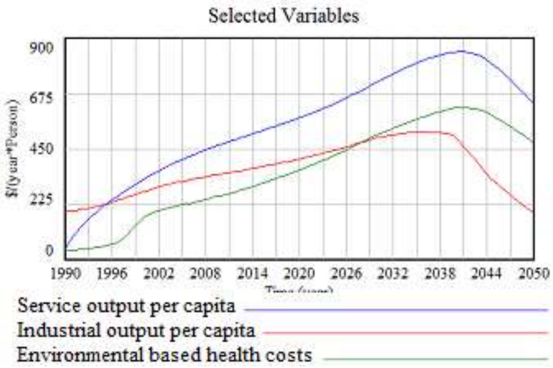

Fig4. Base status simulation results (Red line: Industrial output per capita. Blue line: Service output per capita. Green line: Environmental based health costs per capita)

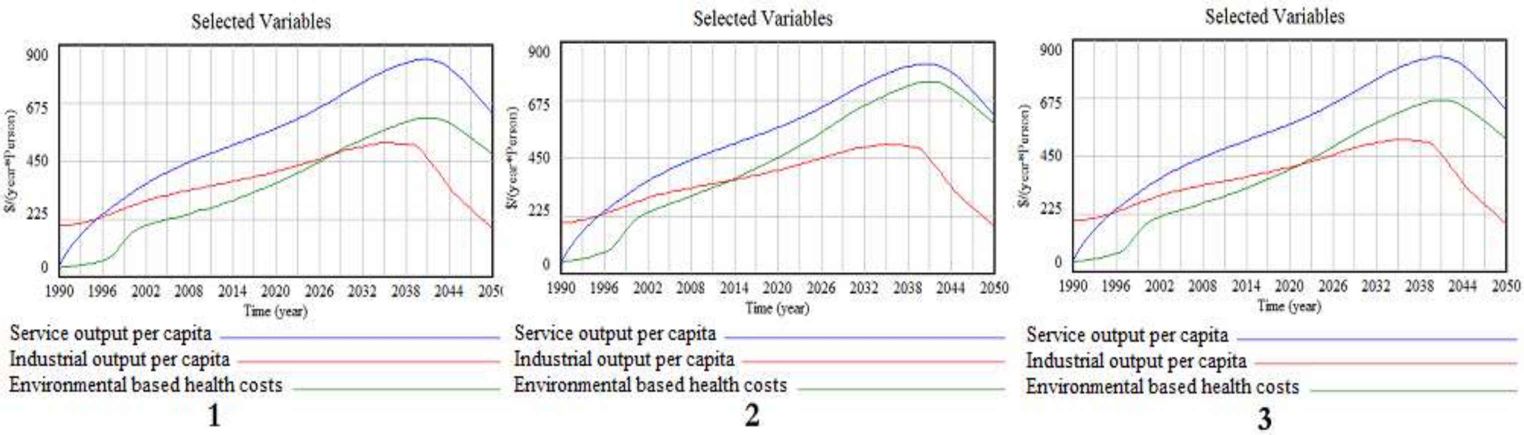

Fig5. Results of changes to lead coordinate (Policies on combustion type/quality, processing quality and utilization fraction of lead materials - industry sector)

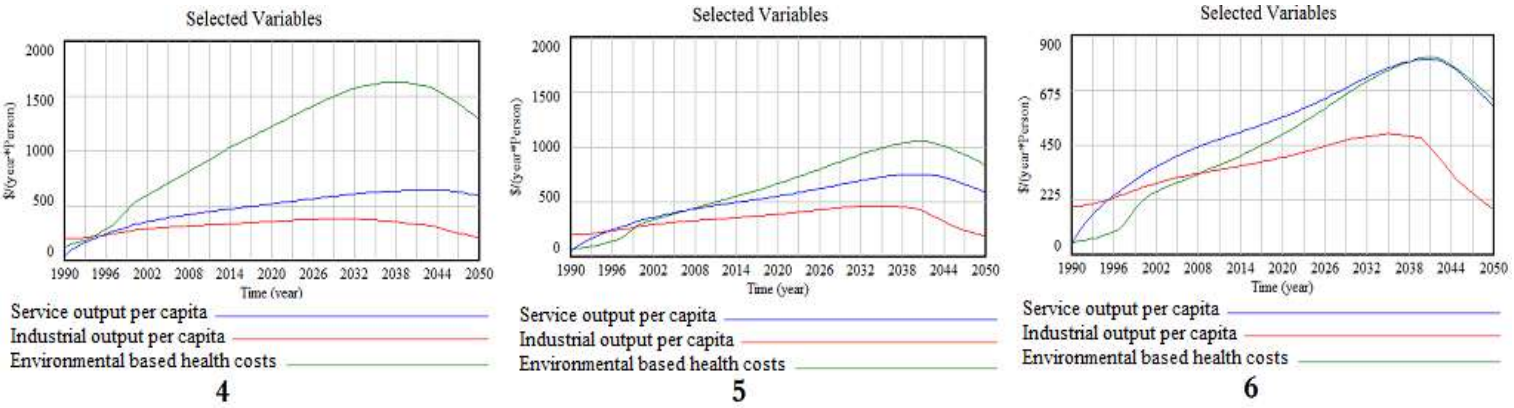

Fig6. Results of changes to NG coordinate (Policies on combustion type/quality, processing quality and utilization fraction of NG materials – Industry sector)

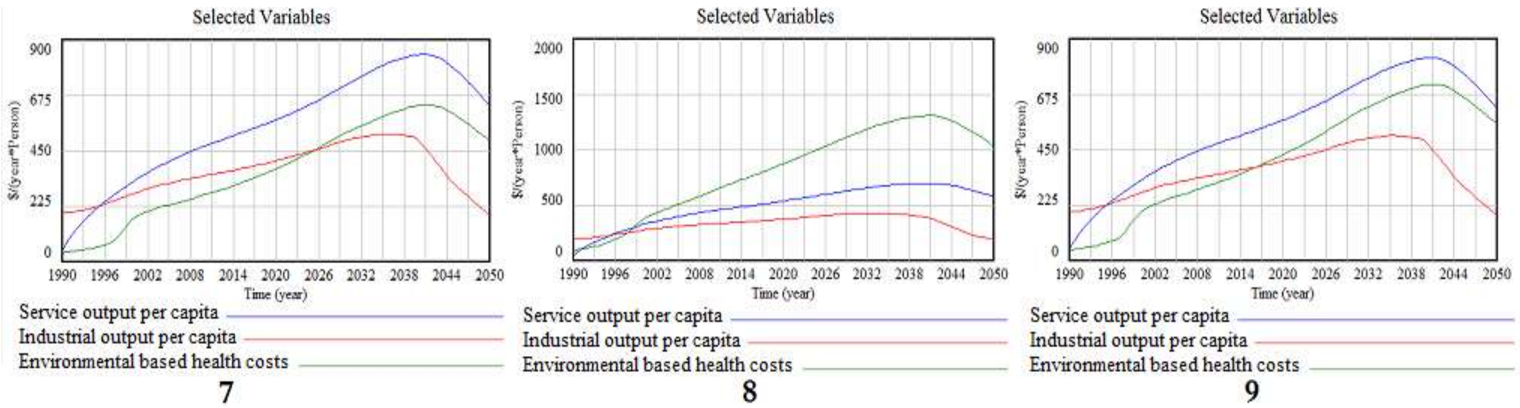

Fig7. Results of changes to Zinc coordinate (Policies on combustion type/quality, processing quality and utilization fraction of Zinc materials – Industry sector)

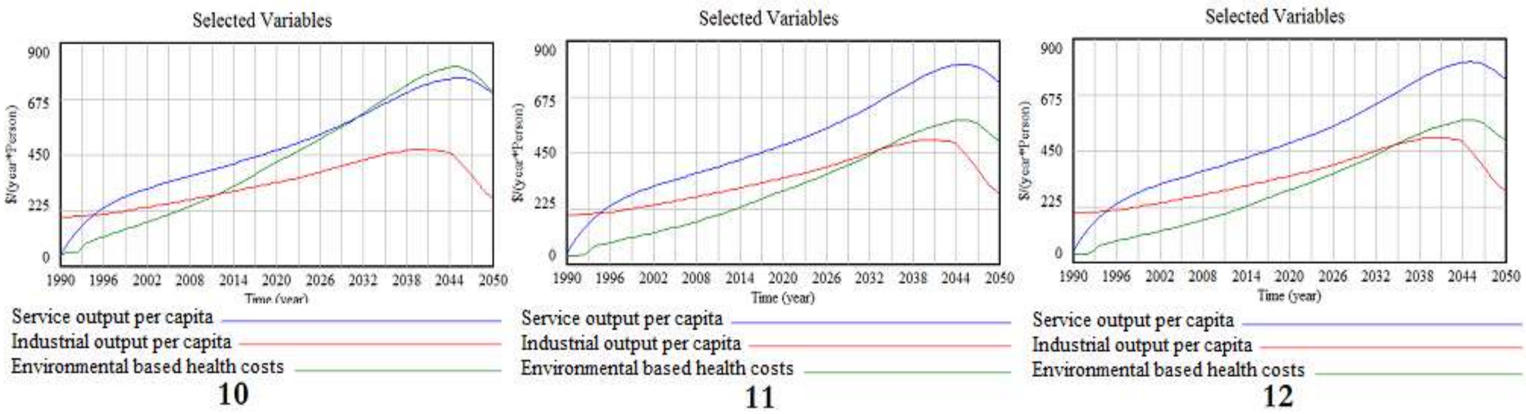

Fig8. Results of changes to Gasoline coordinates (Policies on combustion type/quality, octane number and investment fraction on public transportation – Service sector)

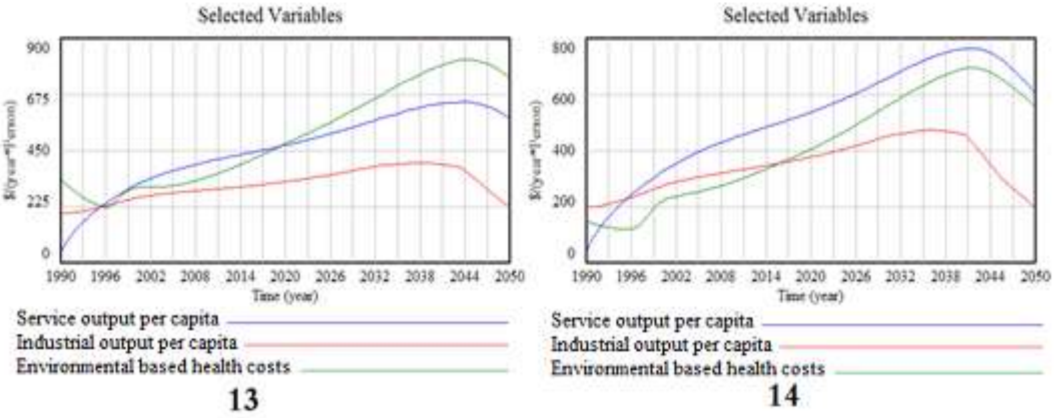

Fig9. Results of changes to Ammonia coordinates (Policies on quality and utilization fraction of fertilizers – Agriculture sector (Arable lands))

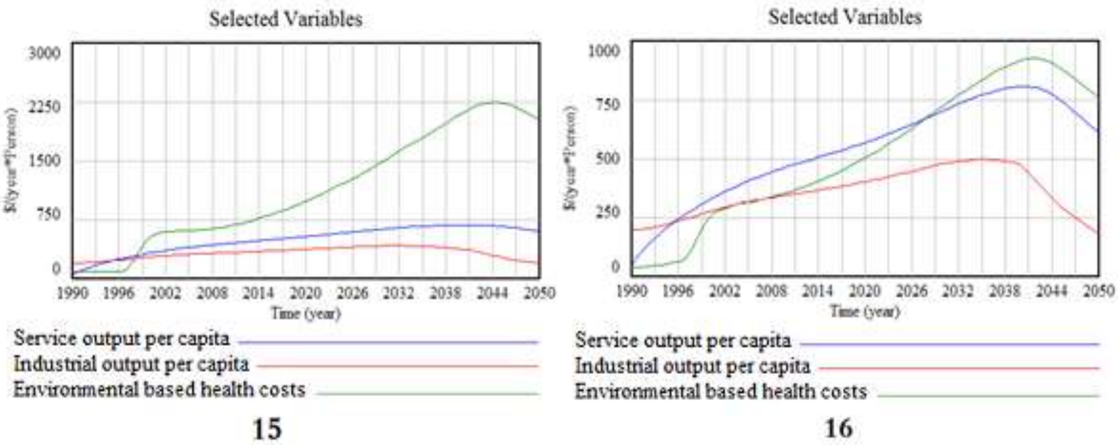

Fig10. Results of changes to particulate matter (PM10) Coordinates (Policies on mulching and green space per capita, Agriculture sector (Non arable lands))

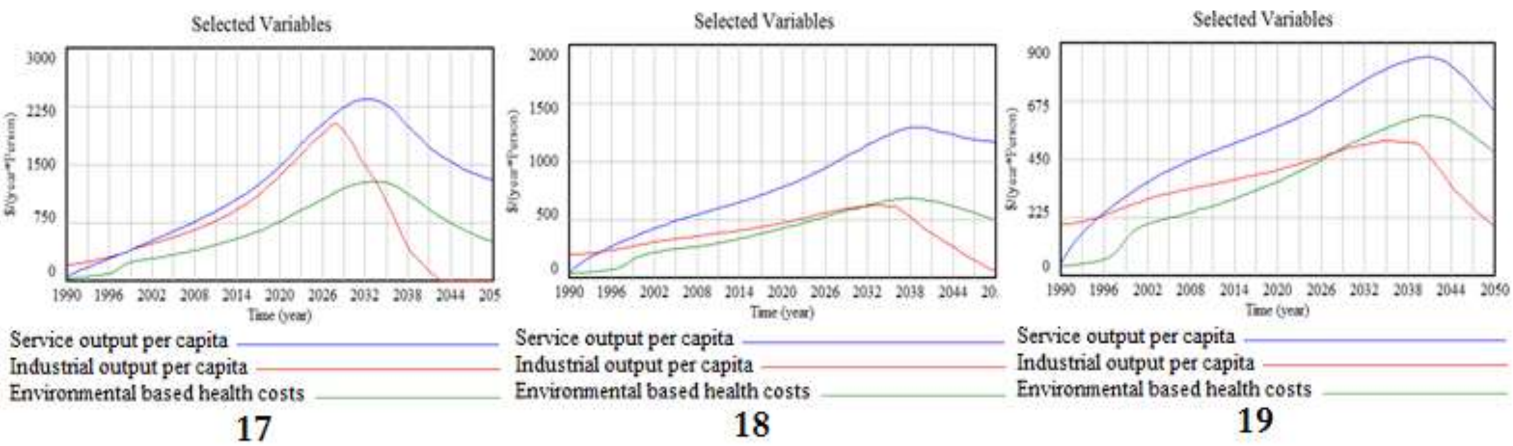

Fig11. Results of changes to the industrial (17), service (18) and agricultural (19) capitals half-lives (Policies on enhancing the quality of repair and maintenance departments)

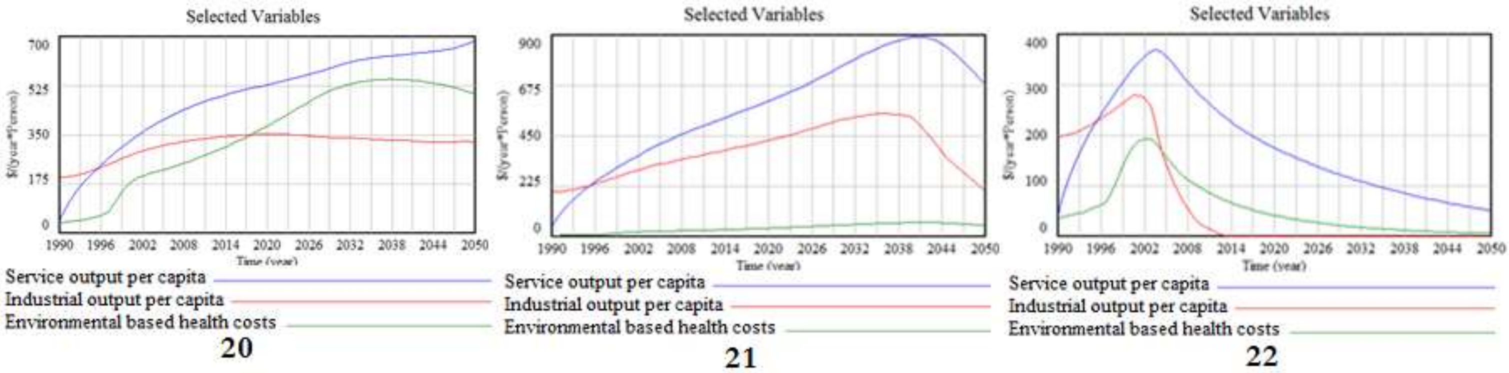

Fig12. Results of changes to pollution absorption time (Policies on desertification and forestation - 20), correlation between pollution and public health costs (Policies on subsidies for public health facilities and culture promotion - 21) and non-renewable resources utilization fraction (Policies on increasing the utilization of renewable resources - 22)

Model validation

This study was validated within two divisions of behavioral and structural validation tests. There are various validation tests and the current study adopted the most important ones. At first the study describes structural validation tests[47] :

- **Dimensional Consistency Test**: according to this test, if a function is the product of other functions of different variables, that function unit needs to be the product of same functions units. *Dimensional validation test* is validated by Vensim software using *unit check* tab available in *Model* menu as Fig13 is indicating.

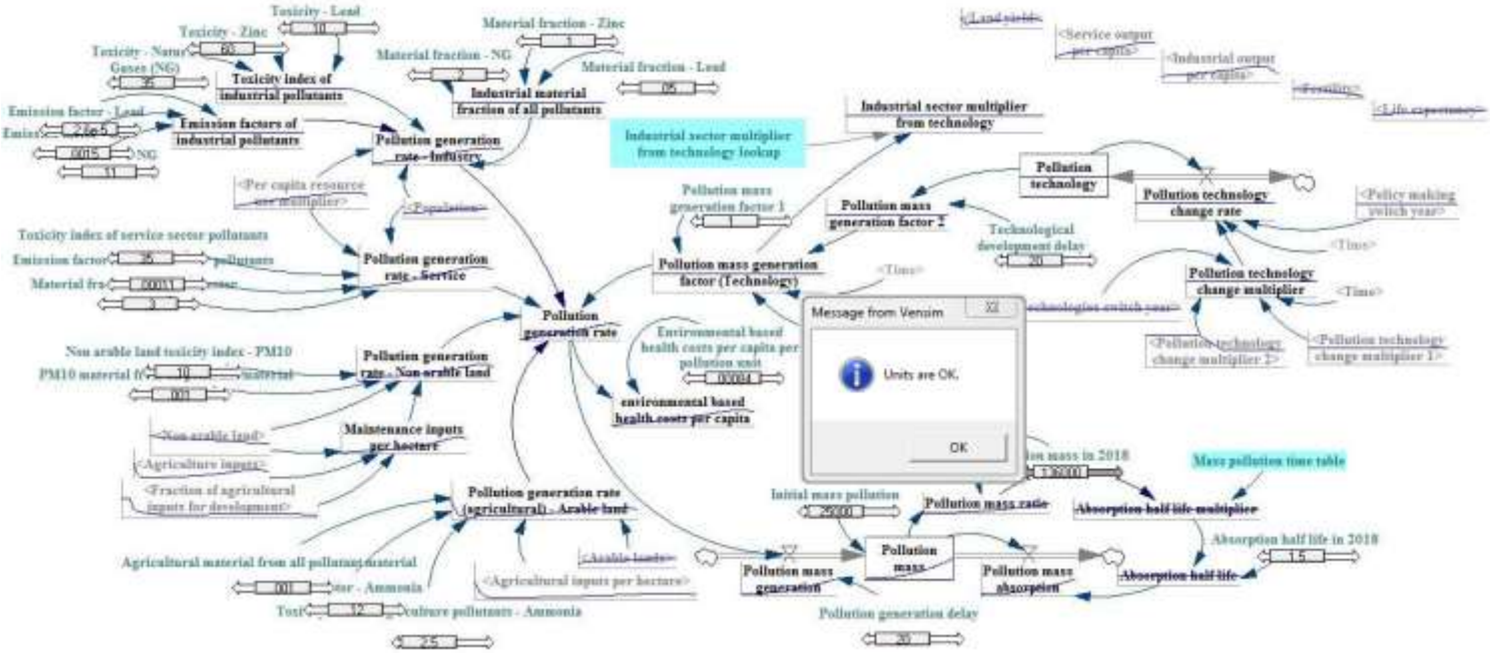

Fig13. Dimensional consistency test

- **Parameter Assessment Test**: In this type of validation, if a variable is the cause of an effect, it could not be the effect of the same cause. Otherwise, the model fails to conduct simulation. This simulation error can be discovered using *checking model* tab as well (Fig14).
-

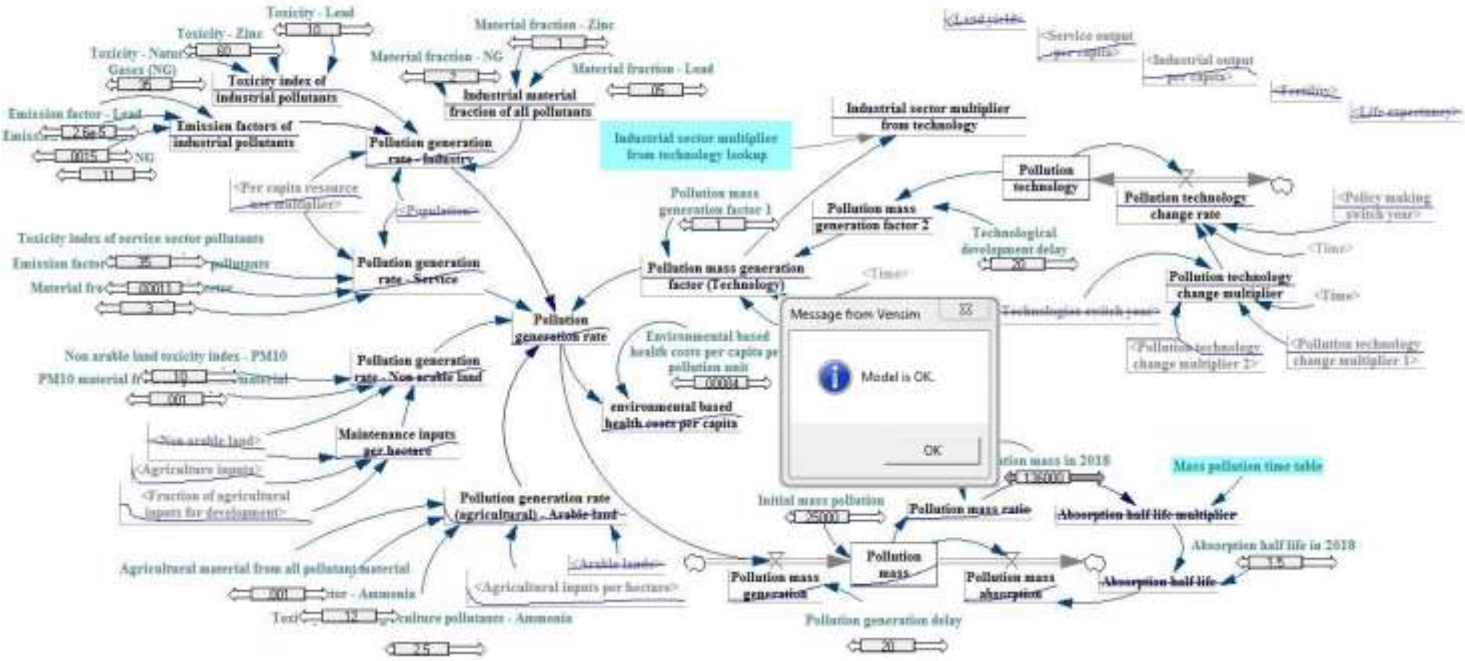

Fig14. Parameter assessment test

- **Boundary Adequacy Test**: This test applies methodologies of interview and survey with experts to explain which variables are selected for which reasons. The study applied the mentioned methods to be noted of experts of SD with environment pertaining backgrounds.
- **Extreme Condition Test**: This test validates the limits of outputs which should not be non-logical and extremely high values. This validation can be implemented by Vensim software. In case of abnormal values for simulation outputs, o*ver flow points* message appears.

Over the behavioral tests sector, the limit assessment of the model will be evaluated which is as follows:

- **Behavior Replication Test**: This validation answers the question that whether the model complies with historical rules and records or not. To meet the requirements of this test, the variables of *population* and *life expectancy* which both values are published and available online (secondary data) have been compared with model outputs of *population* and *life expectancy* indicating a high concordance. According to the [48] and [49], the population (person), life expectancy (year) and annual gross domestic production (GDP) (dollar) of Iran are 81.16 million (Proportion between Iran and Zanjan province is 100 to 1.35), 75 (Proportion between them is 1 to 1) and 1.6 trillion (Proportion between them is 100 to 1) respectively. The simulation results indicate population, life expectancy and annual GDP of Zanjan province are 1.15 million, 75 and 16 billion as well. Based on aforementioned proportions, the concordances of results with published evidences are 0.95, 100 and 0.95 respectively.
-

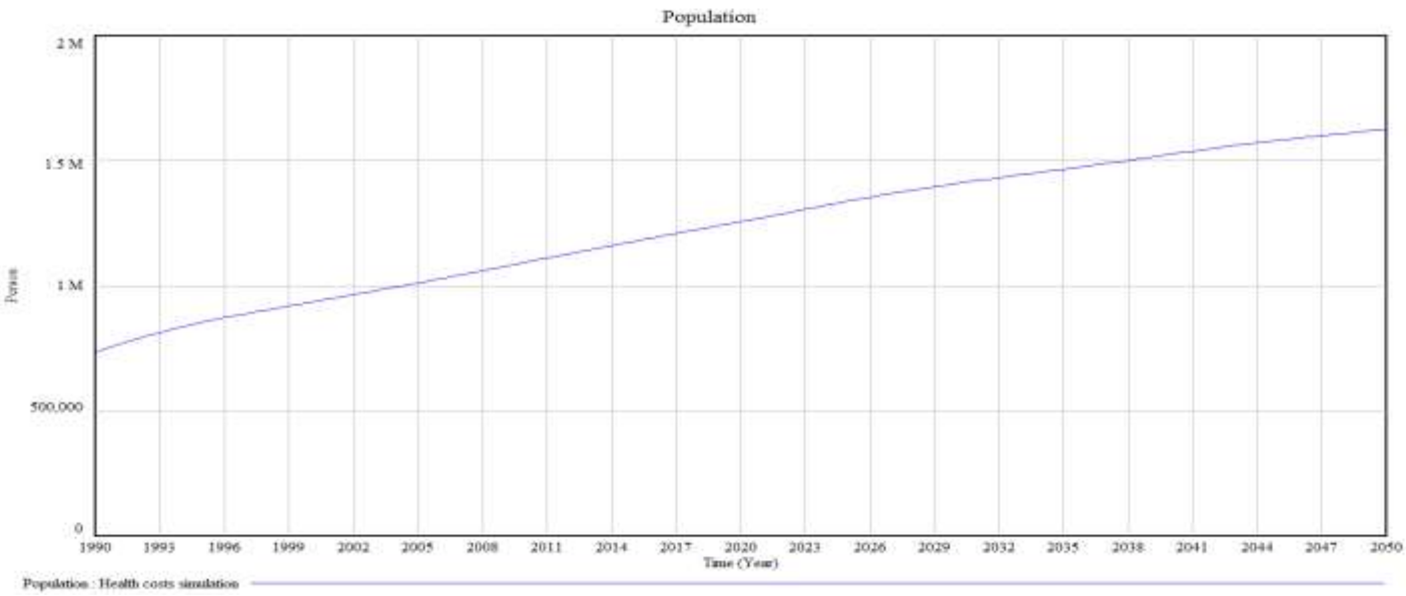

Fig15. Population of Zanjan province based on simulation (1990 – 2018)

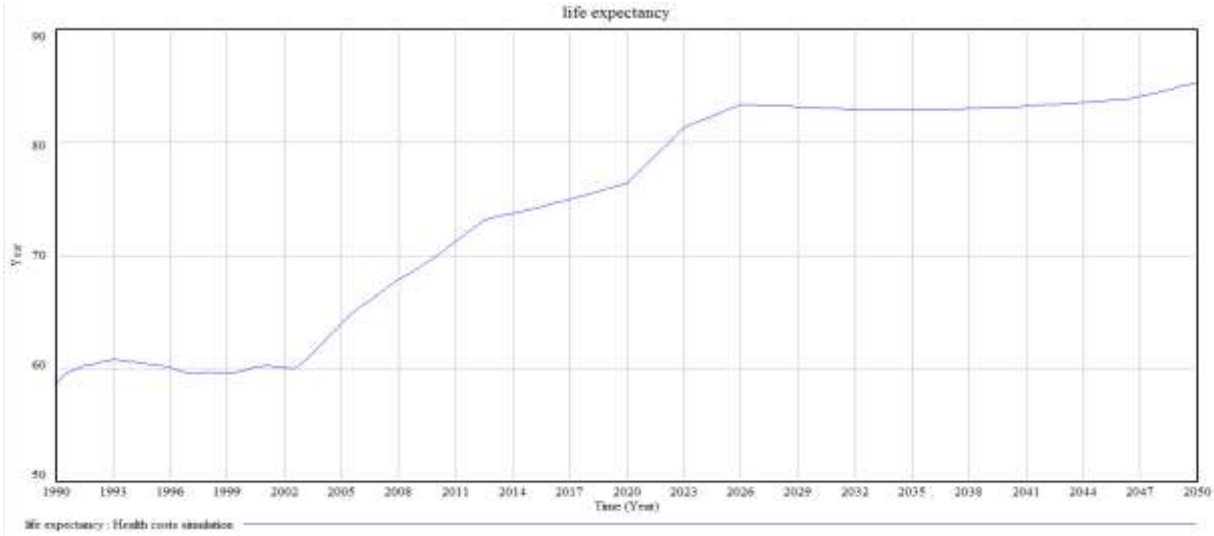

Fig16. Life expectancy of Zanjan province based on simulation (1990 – 2018)

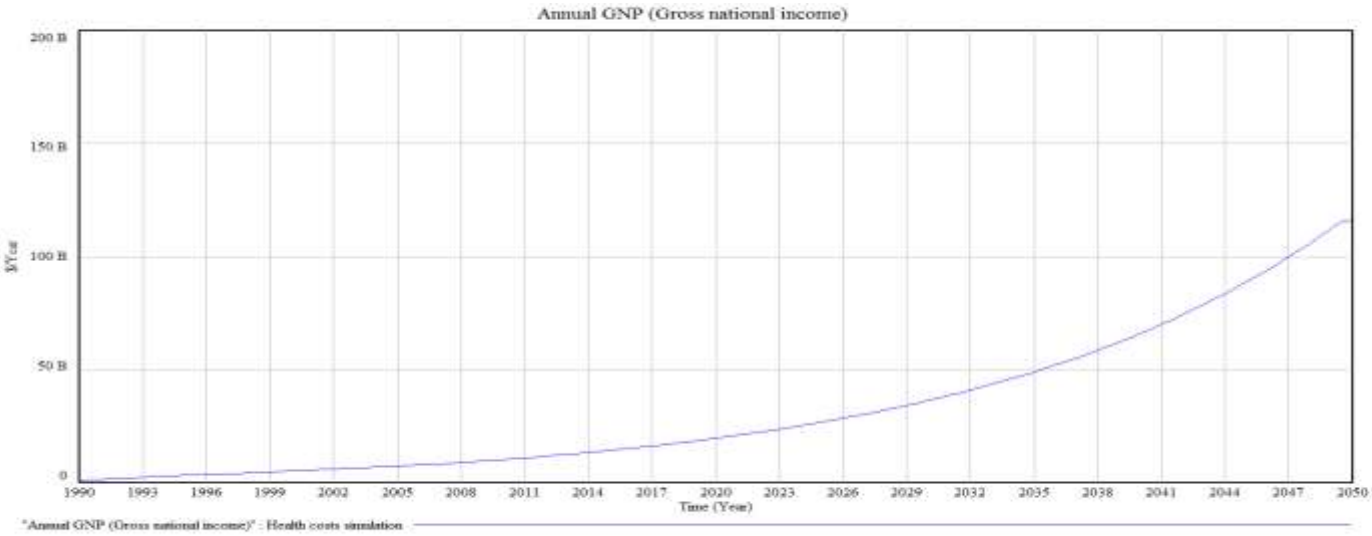

Fig17. Annual GNP of Zanjan province based on simulation (1990 – 2018)

- **Family Member Test.** This test compared the model outputs with those of the most similar city with Zanjan in terms of demographics, geography, culture and agriculture (Qazvin city) and the comparison indicated 99% similarity between corresponding variables outputs of these two cities.

Conclusion

According to the following recommendations, items 1 to 6 (except 5) belongs both regional (Zanjan) and transregional (national) levels. Item 5 concentrates only on regional level whereas items 7 and 8 are associated with transregional policies since these policies should be legislated in national level and cannot be ruled or legally pursued within provincial boundaries. Hence, items 1 to 4 and 6 deal with both levels, item 5 deals only with regional level and items 7 and 8 address transregional policies.

1. Long-term planning for less utilization of non-renewable resources. **Reason**: according to the simulations, making changes to the *non-renewable resources utilization* (reducing) will lead to the most reduction in *environmental based health costs per capita*, *industrial output per capita* and *service output per capita*. Their outputs were reduced by 3, 2.1 and 2.4 times respectively (peak point) - scenario 22).

2. Increasing *industrial capitals half-life* through promoting the quality of *maintenance departments* and reducing depreciation of stocks in inventory. (**Reason**: Increasing *industrial capitals half-life* caused *industrial output per capita* and *service output per capita* to increase by 3 times while there was no considerable effect on *environmental based health costs per capita* - scenario 17).

3. Replacement of fossil fuels with natural gases (NG) and improving the combustion quality of NG. (**Reason**: Increasing emission factor of NG fuels increases *environmental based health costs per capita* by approximately 3 times while this effect was not observed by changing the emission factor of other fossil fuels - scenario 4).

4. Promoting desertification policies (increasing urban areas and green space area per capita) and investing on mulching operations for confronting with the emission of PM 10 particles. (**Reason**: Changing *particulate matter (PM10) toxicity index* have no sensible effect on *industrial and service outputs per capita*, but it has significant effect (by 3 times) on *environmental based health costs per capita* - scenario 15).

5. Utilizing modern technologies to promote the quality of lead and zinc processing in the Zinc & Lead Industrial City of Zanjan Province (low-toxicity processing), extraction of lead and zinc applying modern technologies aiming to reduce emission - affected areas and simultaneously increasing filtration quality by joining international conventions and protocols to reduce the emission of production activities (abiding international standards). (**Reason**: Increasing *toxicity indices of lead and zinc* significantly reduces *service output per capita* (by half) and increases *environmental based health costs per capita* (2.5 times) respectively - scenarios 2 and 8).

6. Investing on public transportation to reduce pollutions, preventing the fertility of precipitation systems in the atmosphere and at the same time preventing vegetation destruction (increasing green space area per capita) aiming to increase the pollution absorption (reducing pollution absorption time). (**Reason**: increasing *pollution absorption rate* reduces *environmental based health costs per capita* and simultaneously makes no change to the *industrial and service output per capita*. It is notable that vegetation and atmosphere are the main sources for pollution absorption - scenario 20).

7. Increasing the service capitals life through enhancing the quality of Iran-made parts of auto-making companies (e.g. by applying reverse engineering) and higher compliance of parts with high octane gasoline (> 90). (**Reason**: increasing *service capitals half-life,* increases the *service output per capita* and at the same time, increasing *the gasoline emission factor* (with normal octane value of 75) causes the *environmental based health costs per capita* to increase (scenarios 10 and 18).

8. Increasing the octane number of normal gasoline for economic purposes (through high compression ratio) and better combustion (by boosting the combustion engine). (**Reason**: increasing the *gasoline emission factor* which means the reduction of its quality (reduction of octane number and combustion quality), increases *environmental based health costs per capita* remarkably (by 15 times) - scenario 10).

The current study was seeking to find out regional and national policy recommendations for reducing environmental pollutions affecting health costs based on a generalizable case study of Zanjan city in Iran. The System Dynamics (SD) methodology has been applied to simulate the dynamics of environmental pollutions of the various factors including those of industrial and non-industrial affecting health costs. According to the simulation, the most prior policies are: "Long-term policies for less exploitation of non-renewable resources", "Increasing the life of industrial capital through the promotion of maintenance and repair units", "Replacing fossil fuels with natural gases and promoting their combustion quality" and "desertification policies to combat the release of solid PM10 particles". These results imply that long term policies to find out a methodology for making a tradeoff in utilization of renewable and nonrenewable energies in order to minimize pollutions derived by them will have a bigger effect on the health costs of Zanjan citizens comparing other policies like desertification and forestation.

Abbreviation

SD: System Dynamic; Gross Domestic Production (GDP); Computational General Equations (CGE). Particulate Matter (PM10);

Competing interests

The authors declare no conflict of interests.

Author's contributions

The corresponding author has been the supervisor of the thesis from which this paper has been extracted. Nasim Ghanbar Tehrani has supervised the second author leading him to collect data, design causal loop diagram and to validate the model. The second author; Ahmad Hashemi has been engaged in the division of stock and flow diagram and its validation, while the third author; Mohammad Vahid Sebt has contributed as co-supervisor for proof reading, paraphrasing and complementary corrections.

Acknowledgements

We thank the managers and personnel of Zanjan University of Medical Sciences for their sincere cooperation by sharing their database with us which provided similar studies in our province.

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Please cite this article as:

Ghanbar Tehrani, Nasim, Hashemi, Ahmad, Sebt, Mohammad Vahid. Dynamic Analysis of Environmental Factors Affecting Health Costs Applying a System Approach (Case Study: Zanjan City, Iran). Int J Hosp Res. 2018; 7 (4).