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Challenges and Opportunities of Industrial Ecology Development in Iran

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ABSTRACT: In developing countries such as Iran it was after economic crises and the increase in price of energy carriers and primary resources that industrial ecology was taken into consideration as a method in industrial states. 941 industrial states in Iran have a high potential in creating material and energy flow networks with the industrial ecology approach to prevent massive energy loss and valuable waste and enable optimization. The aim of this research is to study the challenges and opportunities of industrial ecology development in Iran by reviewing the experiences in Iran and other countries. Industrial states are in two groups in terms of clustering, concentrated and non-concentrated on a certain industry for each of which two examples including Charmshar and Salariyeh state and Semnan state are mentioned and analyzed, respectively. Many challenges were discovered in developing industrial ecology, two of which were more important than the others. The first challenge, an unsuitable clustering of industry in Iran with the industrial ecology approach thus disabling the adequate cooperation between complementary industries of material and energy flow networks and the lack of use of the potential by them. The second challenge, lack of a suitable information database to design and execute material and energy flow networks between industries, and without the necessary information, providing the basic needs for proceedings in relation to industrial ecology will be very difficult.

Key words: Industrial ecology, Industrial states, Iran, Environmental management

INTRODUCTION

The fact that waste cannot be buried or incinerated for much longer is an ever growing worry for governments and societies alike, mostly in developed countries. Some important steps in maintaining a sustainable basis for economic development are optimizing the use of raw materials and recycling industrial and consumer wastes. The first steps of industrial ecology were placed about 25 years ago and since then industrial ecology has affected academia, eco-design, environmental policy, industrial development and business strategy (Allenby, 1999) (This article is proof of the on-going evolution of industrial ecology).

The development of industrial ecology was mainly in developed countries and after desirable results had been achieved developing countries became more interested in executing it in their own industries. Iran has not yet paid interest to the topic of industrial ecology and only recently due to economic crisis and adoption of an austerity policy more interest has been taken into developing efficiency programs. Therefore in the country effort has been put into this issue and this study tries to analyze the challenges and opportunities for the country with the industrial ecology approach considering the similar experiences across the world.

The basic ideas which lead up to industrial ecology surfaced in the 1970's and even before that in the work of Robert Ayres who was one of the first to work in this field. Ayres and his colleagues started analyzing the flow of material and energy, mostly concentrating on energy, in systems which ranged from river basins to entire economies which operated under the industrial metabolism suggestive of energy and food inside an ecological system (Ayres, 2008). In Japan studies with the aim of reducing dependence of economy on material were started and the official title of their planning/research group used the name 'industrial ecology' (Watanabe, 1972). In an important

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but less renowned book published in 1983 by the Belgians the Belgian view on economy was described as industrial ecology instead of the usual monetary flow (Billen G et al., 1983). There was a change in 1989 after Frosch and Gallopoulos' article in an issue of Scientific American. Their article demanded for a new structure in industry which was in the form of an ecosystem with materials even those considered as wastes which flow many interconnected production processes (Frosch, 1992).

One of the aims of Industrial ecology is to determine whether material considered waste in a certain industrial sector can be used as raw material in another sector (Allen and Rosselot, 1994). The aim of a central industrial ecology is to change human production and consumption linear systems into closed loop systems (Lowe and Evans, 1995). There are many aspects to industrial ecology including pollution prevention, product life cycles, design for environment and green accounting (Chertow, 1998). An important concept is to consider processes and industries as interacting systems instead of isolated components in a linear flow system. This provides a foundation to discover ways of connecting plants, industries and other waste producing processes into an interconnected web which can reduce the amount of material that goes into disposal sinks and is lost in the process. Rather than trying to reduce waste form a certain facility (pollution prevention) the focus is changed on minimizing the waste produced by larger systems as a whole and reducing material inflow (Richards et al., 1994).

The aim of this research is to study the challenges and opportunities of industrial ecology development in the industrial states of Iran. Therefore, a field investigation was conducted in a few well known industrial states of Iran such as Semnan state and Charmshahr and Salalriyeh state. Questionnaires and interviews were gathered in the most of the units and the results are presented and discussed due to the other countries experiences. However, in the following the types of eco-industrial development, the role of government, IE time line review, eco industrial park and clustering experiences are discussed. After that according to the previous experiences, industrial states in Iran and their challenges and opportunities are presented.

In industries in Iran studies with concepts similar to industrial ecology have been carried out at a micro-level scale in some industries such as energy consuming industries for example, steel, petrochemical and cement industries. These concepts are mainly intra structural and are solely carried out to reduce energy and primary resource consumption and no outside relationship can be seen between the industries. In rare cases uniformed, informal relationships are present but their numbers are few and negligible. The perspectives acquired from studies carried out in the three primary branches of industrial ecology:

1.Conceptual IE
2.Operational IE
3.Systematic IE

All these branches have played their role in developing IE as a discipline and to provoke the concern for industrial sustainability. Conceptual IE which is related primarily with finding similarities between biological and industrial ecosystems has provided many approaches into how to model industrial ecosystems. The internal mechanisms and their products have been handled using operational IE. Some systemic studies on industrial symbiosis, MFA and urban ecology have tried to comprehend industrial ecosystems and their functions. Industrial ecosystems are based on biological ecosystem and are therefore inseparably linked. In order to identify the link between industrial and biological ecosystems, it is important that research be carried out on both of them in the future in concordance with each other (Harper and Graedel, 2004b).

In terms of the second categorization, only some of Conceptual IE can be seen a few of the refineries and petrochemical factories in the country. One of the problems with this part of carrying out conceptual studies is after designing and setting up an industrial unit where the redesign is unaccepted mainly due to numerous changes that occur in the industry, therefore stopping the effort at the research stage.

Industrial ecology is progressing slowly in the government sector. A successful example is Europe who has been able to execute some of the primary concepts in the design stage. Another one of their achievements is material flow accounting as national accounting data for some of the countries in the union (Ehrenfeld, 2004b).

The evolution of industrial states has already begun in Iran. This evolution is without consideration of environmental problems and industrial ecology concepts. The most important organization involved in developing industrial states and its related issues is the Small Industries and Industrial Parks Organization. Iran Small Industries and Industrial Parks Organization (ISIPO) is a developmental organization which is part of the ministry of industry, mine and trade which was established when the "Iran Small Industries Org." and "Iran Industrial Estate Co." joined forces in the second half of the year 2005 in order to plan and develop industrial areas (ISIPO, 2015).

Industrial ecology and other related subjects have not been given attention in Iran and only scattered and limited studies have been carried out and there are still no proper and fundamental studies on this matter in industry in Iran. The majority of studies carried out in this field are the form of master's thesis and the subject is not even mentioned in thesis at a doctorate standard. There are 5 theses in regards to industrial ecology in Iran's universities and they are all based on designing environments with the industrial ecology concept and increasing the environments stability and no engineering work has been performed.

In the first ten years of industrial ecology's mentioning, it was only mentioned in specialized groups especially institutions and it was not yet widespread (Ehrenfeld, 2004a). As a newly proposed topic, industrial ecology was discussed in different assemblies and its design, operation and performance concepts were discussed and analyzed through different perspectives. It was also tried to make quantitative and specific models of the concepts with consideration of the complications in reality based on the aims intended by industrial ecology. One things which was missing in the start was the lack of a general database for designing and studying industrial ecology. Therefore industrial systems were analyzed and many studies were carried out in this field and databases with the aim of feeding industrial ecology started to form (Harper and Graedel, 2004b).

At the start of the second decade industrial ecology was more mature. Although this maturity was accompanied with doubts and many specialists were worried about the results of industrial ecology. In other words the future of developing this plan was not predictable. The aims of IE are justifiable however the path to reach them is not clear and has many doubts (Harper and Graedel, 2004a). After the year 2003, industrial mainly focused on Life Cycle Assessment (LCA) and Life Cycle Inventory databases (LCI database). LCA is a systematic tool for identifying opportunities and increasing awareness of the environmental effects of different topics and products. Life cycle analysis databases in Iran's industry have not been studied much and lack comprehensive detail and suitability for industrial ecology design. Lack of LCI databases is one of the biggest problems that developing industrial ecology faces. Even though Institute of standards and Industrial Research of Iran has provided industries with the framework and principles of LCA, still now comprehensive study on collecting data for LCI database has been carried out. In table 1 a review of the previous studies from 2000 to 2015 has been arranged. The aim of the table was to present from the studies carried out in previous years from the beginning of the rise of industrial ecology those studies which are more important.

In smaller and more widespread industrial developments, the cost of quantities and transportation reduces the economics of scale for reprocessing, therefore that many waste products have to be transferred to centers elsewhere to be processed or disposed. Therefore industrial ecology has the potential to create opportunities to increase the value of industrial production through synergies and business networks that form naturally in clusters. This potential is only just beginning to be realized in many countries (Roberts, 2004b).

MATERIALS & METHODS

To IE in Iran, two industrial well known industrial states are chosen. By interviewing more than 50% of the active unites the challenges and opportunities of IE development were surveyed. In the following, brief descriptions are given. According to the official statistics of Iran Small Industries and Industrial Parks Organization (ISIPO) by the end of the year 2014, a total of 941 industrial states were established in Iran 754 of which are active and functioning. Over 33000 acres of land with industrial use were donated towards this cause to industrial units. There are a total of 34252 industrial units and 2429 workshops are active in these areas and have been able to directly create over 700000 job opportunities. Even though ISIPO tries to create the necessary infrastructure for industrial states, the growth rate of the states compared to their infrastructure is higher. This issue is worrying especially in environmental infrastructures. A briefing of ISIPO statistics have been stated.

After reviewing the studies in Iran we can conclude that almost no work has been done in Iran's industrial states with the industrial ecology approach. By an overview study of Iran's industrial states we can categorize them into two groups:

1-First group: the state concentrates on one particular industry

2-Second group: no criteria have been mentioned and industries have been established based on the investor's demands.

In both scenarios the concepts of industrial ecology have been overlooked in Iran. However considering even a few of ISIPO concepts can be beneficial in terms of the environment and economy for the industrial state, region and country. In this section two industrial states were categorized based on the criteria mentioned before and were analyzed from an industrial ecology aspect. Fig. 1 shows the geographic location of the two states.

Table 1. Literature review of industrial ecology

	Author	Abstract
1	(Baas et al., 2000)	This paper describes the first four years' experiences with Erasmus University's "International Off-Campus PhD Program on Cleaner Production, Cleaner Products, IE and Sustainability".
2	(Korhonen, 2001)	The local/regional industrial ecosystem approach is reflected in two examples including: regional economic systems of forest industry and energy supply in Finland.
3	(Singhal and Kapur, 2002)	They examined the relevance of industrial symbiosis and carrying capacity concepts and proposes an integrated approach towards IE planning in India.
4	(Korhonen et al., 2004)	This paper studied applications of the IE concept in a research project of Technology and Climate Change (CLIMTECH) Research in Finland.
5	(Seager and Theis, 2004)	This paper proposes an overarching taxonomy for classifying the quantitative criteria of sustainability as financial, thermodynamic, environmental, ecological, socio-political or aggregated.
6	(Chiu and Yong, 2004)	This paper considered the possibilities to develop an eco-industrial development (EID) strategy for these developing countries.
7	(Korhonen, 2004)	This paper evaluates the concept of IE by considering its application and use in terms of the strategic sustainable development model.
8	(Kuo et al., 2005)	They integrated framework for studying boxed food was based on material flow analysis and LCA with the Hazard Analysis Control Point (HACCP) system.
9	(Dewulf and Van Langenhove, 2005)	This paper focused on integrating IE principles into a set of environmental sustainability indicators for technology assessment.
10	(Diwekar, 2005)	This paper presents a systems analysis perspective that extends the traditional process design framework to green process design and IE leading to sustainability.
11	(Phillips et al., 2006)	UK county waste minimization program was evaluated based on the requirement for regional facilitated development of IE.
12	(Basu and Van Zyl, 2006)	This paper provides a review of environmental management practices in the mining and minerals industry, emphasizing two concepts: IE and cleaner production.
13	(Cervantes, 2007)	This paper describes a way of teaching IE and to show some tools that may help for the IE teaching by the development of lectures, practical lessons and projects on real industrial ecosystems.
14	(Wang et al., 2008)	This research is intended to offer corresponding countermeasures to make the development of resource-based industrial cluster as a sustainable industry.
15	(DeLaurentis and Ayyalasomayajula, 2009)	This paper explores the relationships among the constructs of complex adaptive systems, systems of systems, and IE.
16	(Sun and Zhou, 2010)	The paper presents a dynamic optimal control model with the aim of achieving industrial ecological conversion optimization and satisfying the requirements of sustainable development in resource-based city.
17	(Ardente et al., 2010)	The paper presents an application of the Life-Cycle Assessment (LCA) to the planning and environmental management of an "eco-industrial cluster."
18	(Ruiz, 2011)	This article studied planning and design of an industrial area is quite a complicated process, due to the large number of agents involved.
19	(Albu, 2011)	This paper presents the concept of industrial ecology and gives some examples of new business ideas built and developed on it.
20	(Petrie et al., 2012)	This chapter describes ways to enhance the operational potential of Industrial Ecology and focuses on the distributed decision making practices of individual agents within networks of industry, business and government.
21	(Liu and Zhang, 2013)	This paper examined the case of water utilization practice based IE of the Hai Hua Group (HHG) in China.
22	(Boons, 2013)	The chapter presents an overview of research on the way in which global companies deal with their ecological impact in relation to the theory of ecological modernization.
23	(Schiller et al., 2014)	In this paper Social-Material Network Analyses studies were classify and the body of work, drawing on network analyses from various disciplines were discuss.
24	(Cerceau et al., 2014)	This article presents the result of a research project (2011-2012) consisting of an international inventory of innovative resource management initiatives in 18 port areas.
25	(Xu et al., 2015)	In this article, a new data base "big data" is presented and discussed how can help IE.
26	(Smith et al., 2015a,)	A methodology is presented to consider individual waste-to-energy or waste-to-product system synergies, evaluating the economic and environmental issues associated with each system.

Table 2. Environmental projects in industrial states (Status of environmental projects at the end of 2004)

	Topic	Unit	Number	Percentage compared to all active states in Iran
1	Active filtering plants	Filtering plant	358	47.50%
2	Filtering plants under construction	State and region	30	4.00%
3	Filtering plants being designed	State and region	56	7.40%
4	Sewage network	State and region	300	39.80%
5	Reuse of waste water	State and region	46	6.10%
6	Quantitative and qualitative study of waste	System	40	5.30%
7	Environmental analysis projects	State and region	195	25.90%
8	Establishing ISO 14001 in sewage treatment plants	State and region	40	5.30%
9	Number of fire stations	State and region	171	22.70%

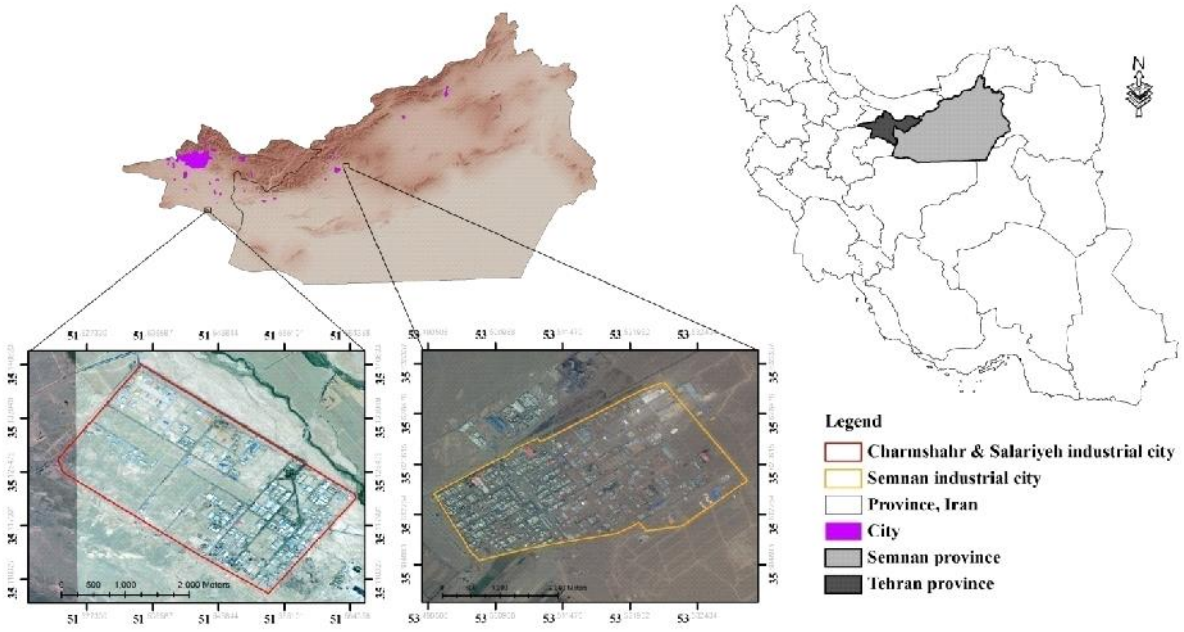

Fig. 1. Geographic location of the two states being studied

Charmshahr and Salariyeh industrial state is located in the most southern part of Varamin city and stretches across 704 acres of land and according to the information acquired from the board of governors of the industrial state, the specifications of the units established in the state are shown in Table 3.

This state can mentioned as a clear example of the first group of industrial states in Iran (states concentrated on one type of industry). The main focus of this state based on the categorization of ISIPO is leather. As mentioned before in the table over 55% of active industries in the state are part of the leather industry. The sitting of the leather industries in the state is such that they are mostly to one side of the state and other industries are in other areas. Considering the large number of leather industries in the waste related to them is also a lot. For example wool is a common waste in this industry and considering there is no other industry to use this wool, it is taken to a burial site and deposited. The deposit site in summer time due a temperature rise catches fire and causes many problems for the area. However by establishing an industrial unit such as wool spinning,

Table 3. Condition of industrial units in Charmshahr and Salariyeh industrial state

	Type of activity and industrial field	Number of active units	Percentage
1	Electricity and electronics	0	0.00%
2	Utility service	35	16.60%
3	Cellulose	0	0.00%
4	Chemical	52	24.60%
5	Food	4	1.90%
6	Metal and non-metal	4	1.90%
7	Textile (leather)	116	55%
8	Total	211	100%

all of the waste wool can be used as the primary resource for this industry. However ISIPO keeps increasing the number of Tanning units based on clustering, whereas by changing its perspective to industrial ecology it could solve the state's problems through simpler and more efficient methods by introducing suitable industries to the state and reducing the produced waste volume. With initial studies and analysis on the material flow model and after analysis of the produced waste in this state it can be predicted that over 50% of the produced waste can be reused in other units of the industrial state and it is only because there is no suitable industry available and the fact it is not cost effective to transport the waste to the nearest suitable industrial unit that a large volume of unusable waste is transferred to burial zones. Semnan industrial state was established with the aim of concentrating industries in the year 1364 and construction of necessary infrastructures and providing basic services such as gas network, central sewage filtering plant, water distribution facility and network and electricity distribution network were part of the plans for this state. This state is 2000 acres across and is located at the 8th kilometer of the Semnan-Damghan road. The operational area of this state is approximately 1000 acres where the industrial lands make up for 650 acres. At the moment 300 industrial units are working in this state which provide over 8000 job opportunities. Table 4 shows the specifications of Semnan industrial state.

Semnan industrial state is an example of the second group meaning states which follow no specific criteria for establishing industries and industrial units are established based only on the investors of the state. These states were mainly established to answer the needs of nearby cities and there are only few major industries available. Another weakness in these states is the high number of assembly industries. In these industries mainly assembly services are performed which are generally neutral units in industrial ecology. Because their primary resource is components and their only waste is plastic and cardboard boxes. Another problem with these states is the random site selection

Table 4. Functional units located at Semnan industrial state

	Type of activity and Industrial field	Number of active units	Percentage
1	Food	21	7.0%
2	Chemical	82	27.3%
3	Metal	96	32.0%
4	Cellulose	13	4.3%
5	Electricity and Electronics	16	5.3%
6	Textile	23	7.7%
7	Utility service	25	8.3%
8	Non-metallic minerals	16	5.3%
9	Other	8	2.7%
10	Total	300	100%

based on the initial agreement on the purpose of use of the state's lands and lack of any consideration for any kind of potential measurement between units in terms of energy and material transfer. ISIPO can improve the condition of the units by reconsidering the site selection and clustering of industries in these states and providing the necessary basis for communication between the units with the concepts of industrial ecology in terms of location and distance. With preliminary analysis which was carried out on the material flow model and analysis of produced waste in this state it is predicted that 30 percent of the produced waste has to the potential to be reused in other units of the states.

RESULTS & DISCUSSION

Considering the studies carried out on industrial states that have an industrial ecology approach, the following challenges and opportunities can be mentioned for industrial ecology in Iran.

The most important challenge in ignoring industrial ecology in Iran is the lack of material and energy flow in industrial states and therefore wasting energy and waste. This issue causes additional costs such as burying waste, spread of pollution, increase of disease especially cancer in surrounding areas, medical costs and so on. Moreover, lack of suitable site selection for industrial units based on the possibility of creating a waste and energy flow between them. Useful information about rectifying industrial clustering with an industrial ecology approach exists and it can be used to improve in this area, for example the rectified clustering in industrial cities in Australia (Roberts, 2004a) can be a good example in making changes in industrial states in Iran.

Unsuitable clustering of industries and not considering complementary communications between industrial clusters in case of creating material flow between them. It is worth mentioning that if the industrial state is in the primary design stage the placement and site selection of industrial units and clusters can be optimized based on the material flow model. However this is not possible in industrial states which are already built. Two points are important in industrial states which are currently active in Iran. The first point is the material flow model considering the current location of industrial units in relation to each other and the second point is industrial units which are partially or completely inactive. A problem which has surfaced in the country in recent years due to economic crises and international sanctions, is inactivity and empty lands in industrial states. These lands are mainly dispersed between active industries and if their use was reconsidered the necessary basis for establishing plants with consideration of industrial ecology design, material flow model and the least possible distance between industries for material and energy transfer, would be provided. In other words this issue gives the managers of the industrial states the chance to fill in the missing pieces to the industrial ecology puzzle and to get closer to optimum results. Another issue is the existence of assembly and utility service industries in the state as industries which cannot use waste. Also not having fundamental and heavy industries such as steel, copper, petrochemical, refinery near the industrial states leads to not using valuable waste and energy in these industries. The best combination for an industrial state is the combination of small and large industries together. However having similar industries both in terms of size and type limits material and energy flow between them. A suitable example of this combination is Kalundborg industrial states.

However, there is too much concentration on a certain industry and therefore creating too much of a certain waste and not being able to create an equilibrium in material flow. One way to tackle this in the design stage is using innovative optimizing systems in order to acquire an optimal combination of industries in terms of location, production volume and also their quantity. Also using recycling and recovery hubs for preprocessing and preparation of wastes (as a middle units) so it can be used in other industries is worth consideration. In addition, there is a low variety in industrial units and therefore limitation in creating material flow. In countries such as Iran where the majority of the country's needs are provided through imports, the government can help by guide foreign investments in order to import new technologies and industries to industrial states. One of the guidance factors of industries can be completing the material flow in industrial states with industrial ecology concepts. For example an industry is in priority to enter the industrial state which consumes more of the waste as primary resources or the government prioritizes grants and subsides to these industries.

Another subject is the very low knowledge of industries on concepts of industrial ecology and therefore their lack of cooperation in developing material flow. Even with all the mentioned problems in developing industrial ecology in the country's industrial states, there is still considerable potential in creating a flow in waste material between existing industrial units but the main reason such a flow does not exist between them is the lack of knowledge of these units in relation to each other. Generally units in the state work as islands and have no connection to

other units in the state and only some wastes such as cardboard boxes, nylon, plastic, and aluminum are recovered, collected and transferred outside the state in order to be recycled. However by establishing communication between the units material flow is possible.

Industrial ecology is followed by the culture for saving and recycling material, waste and energy. The necessities for such a culture are knowledge, information and communication. The lack of one of these three elements is the country's main problem in the industry sector and excessive and inefficient use of material and energy. With general analysis of material and energy waste in Iran's industries, the priority in creating energy and material flow can be placed on items such as petrochemical waste, refineries, city waste, high temperature waste water, steam, and industrial waste water so they can be recycled. These wastes are valuable and accessible and any system which enables their reuse is necessary.

Finally Lack of a suitable, complete and exact database in order to carry out primary industrial ecology studies is one of the main problems of industrial ecology development. The studies carried out on produced waste in some states are general waste management studies which lack the accuracy and quality needed to create a material flow model. Information such as production processes of each plant, waste analysis, input material analysis and energy consumption are required for industrial ecology studies. Creating software such as websites and online databases considerably helps in this matter. Life cycle analysis and creating databases on it such as LCI are among the fundamental needs for industrial ecology studies which have to be completed in the second stage after creating the primary database for waste and input material and processes.

CONCLUSIONS

In this study by analyzing Iran and the world's experiences, the challenges and opportunities were analyzed in Iran. The challenges and opportunities of industrial ecology are analyzed in detailed in this study and the main two are mentioned below:

By an overall analysis of industrial states in Iran it can be concluded that their layout and clustering is divided into two types. Industrial states focused on one type of industry or states established based on the investors demands, while, in neither scenario the flow of material and energy have been considered and the concepts of industrial ecology have been overlooked. Correcting the rules of industrial clustering in the country is necessary. Moreover, two well-known industrial states due to the mentioned categorization were studied as examples. Industrial states are categorized in two groups in terms of clustering, concentrated (Charmshar and Salariyeh state) and non-concentrated (Semnan state) on a certain industry. Another big challenge is the lack of a suitable and complete database. The weak function of the ministry of industry, mine and trade and the environment protection organization of Iran are accountable for this flaw. With the lack of a local database, industrial ecology designers are in an indefinite and vague position and are not able to design and suggest an optimal model for material flow on a regional scale and even in one industrial state. However, this issue is detectable in the study areas and the interviews.

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REFERENCES

Albu, A. (2011). Business innovation using industrial ecology. Metalurgia International, **16,** 36-39.

Allen, D. T. and Rosselot, K. S. (1994). Pollution prevention at the macro scale: flows of wastes, industrial ecology and life cycle analyses. Waste Management, **14,** 317-328.

Allenby, B. (1999). Culture and industrial ecology. Journal of Industrial Ecology, **3,** 2-4.

Ardente, F., Cellura, M., Brano, V. L. and Mistretta, M. (2010). Life cycle assessment-driven selection of industrial ecology strategies. Integrated Environmental Assessment and Management, **6,** 52-60.

Ayres, J. (2008). A call for national strategies for environment and health. The Lancet, **371,** 302.

Baas, L. W., Huisingh, D. and Hafkamp, W. A. (2000). Four years of experience with Erasmus University's "International Off-Campus PhD programme on cleaner production, cleaner products, industrial ecology and sustainability". Journal of Cleaner Production, **8,** 425-431.

Basu, A. J. and Vav Zyk, D. J. A. (2006). Industrial ecology framework for achieving cleaner production in the mining and minerals industry. Journal of Cleaner Production, **14,** 299-304.

Billen, G. Toussaint, F, Peeters, P., Sapir, M., Steenhout, A. And J-P, V. (1983). L'e´cosyste'me belgique. Essai d'e´cologie industrielle. Centre de Recherche et d'Information socio-politique (CRISP).

Boons, F. (2013). Ecological Modernization and Industrial Ecology. The Handbook of Global Companies.

Cerceau, J., Mat, N., Junqua, G., Lin, L., Laforest, V. And Gonzalez, C. (2014). Implementing industrial ecology in port cities: international overview of case studies and cross-case analysis. Journal of Cleaner Production, **74,** 1-16.

Cervantes, G. (2007). A methodology for teaching industrial ecology. International Journal of Sustainability in Higher Education, **8,** 131-141.

Chertow, M. R. (1998). Waste, Industrial Ecology, and Sustainability. Social Research, **65,** 31-53.

Chiu, A. S. F. And Yong, G. (2004). On the industrial ecology potential in Asian Developing Countries. Journal of Cleaner Production, **12,** 1037-1045.

Delaurentis, D. A. And Ayyalasomayajula, S. (2009). Exploring the synergy between industrial ecology and system of systems to understand complexity a case study in air transportation. Journal of Industrial Ecology, **13,** 247-263.

Dewulf, J. and Van Langenhove, H. (2005). Integrating industrial ecology principles into a set of environmental sustainability indicators for technology assessment. Resources, Conservation and Recycling, **43,** 419-432.

Diwekar, U. (2005). Green process design, industrial ecology, and sustainability: A systems analysis perspective. Resources, Conservation and Recycling, **44,** 215-235.

Ehrenfeld, J. (2004a). Industrial ecology: A new field or only a metaphor? Journal of Cleaner Production, **12,** 825-831.

Ehrenfeld, J. R. (2004b). Can industrial ecology be the "science of sustainability"? Journal of Industrial Ecology, **8,** 1-3.

Enright, M. (2000). The globalisation of competition and the localization of competitive advantage: policies towards regional clustering, The globalisation of multinational enterprise activity and economic development., McMillian Press.

Frosch, R. A. (1992). Industrial ecology: A philosophical introduction. Proceedings of the National Academy of Sciences of the United States of America, **89,** 800-803.

Harper, E. M. And Graedel, T. E. (2004a). Industrial ecology: A teenager's progress. Technology in Society, **26,** 433-445.

Harper, E. M. And Graedel, T. E. (2004b). Industrial ecology: a teenager's progress. Technology in Society, **26,** 433-445.

Korhonen, J. (2001). Regional industrial ecology: examples from regional economic systems of forest industry and energy supply in Finland. Journal of Environmental Management, **63,** 367-375.

Korhonen, J. (2004). Industrial ecology in the strategic sustainable development model: strategic applications of industrial ecology. Journal of Cleaner Production, **12,** 809-823.

Korhonen, J., Savolainen, I. And Ohlström, M. (2004). Applications of the industrial ecology concept in a research project: Technology and Climate Change (CLIMTECH) Research in Finland. Journal of Cleaner Production, **12,** 1087-1097.

Kuo, N. W., Hsiao, T. Y. And Lan, C. F. (2005). Tourism management and industrial ecology: A case study of food service in Taiwan. Tourism Management, **26,** 503-508.

Liu, C. And Zhang, K. (2013). Industrial ecology and water utilization of the marine chemical industry: A case study of Hai Hua Group (HHG), China. Resources, Conservation and Recycling, **70,** 78-85.

Lowe, E. A. And Evans, L. K. (1995). Industrial ecology and industrial ecosystems. Journal of Cleaner Production, **3,** 47-53.

Petrie, J., Kempener, R. And Beck, J. (2012). Industrial ecology and sustainable development: Dynamics, future uncertainty and distributed decision making. Sustainability: Multi-Disciplinary Perspectives.

Phillips, P. S., Barnes, R., Bates, M. P. And Coskeran, T. (2006). A critical appraisal of an UK county waste minimisation programme: The requirement for regional facilitated development of industrial symbiosis/ecology. Resources, Conservation and Recycling, **46,** 242-264.

Richards, D. J., Allenby, B. R. And Frosch, R. A. (1994). The greening of industrial ecosystems. In: Allenby,B.R.,Richards,D.J. (Eds.), The Greening of Industrial Ecosystems, Washington, DC, National Academy Press.

Roberts, B. H. (2004a). The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: An Australian case study. Journal of Cleaner Production, **12,** 997-1010.

Roberts, B. H. (2004b). The application of industrial ecology principles and planning guidelines for the development of eco-industrial parks: an Australian case study. Journal of Cleaner Production, **12,** 997-1010.

Ruiz, M. C. (2011). Industrial ecology in the planning and management of industrial parks. Environmental Planning.

Schiller, F., Penn, A. S. And Basson, L. (2014). Analyzing networks in industrial ecology – a review of Social-Material Network Analyses. Journal of Cleaner Production, **76,** 1-11.

Seager, T. P. And Theis, T. L. (2004). A taxonomy of metrics for testing the industrial ecology hypotheses and application to design of freezer insulation. Journal of Cleaner Production, 12**,** 865-875.

Singhal, S. And Kapur, A. (2002). Industrial estate planning and management in India—an integrated approach towards industrial ecology. Journal of Environmental Management, **66,** 19-29.

Smith, R. L., Sengupta, D., Takkellapati, S. And Lee, C. C. (2015a). An industrial ecology approach to municipal solid waste management: I. Methodology. Resources, Conservation and Recycling.

Sun, X. And Zhou, M. (2010). Year. Performance evaluation of transformation of industrial ecology in the resource-based

cities. In: Proceedings of the International Conference on E-Business and E-Government, ICEE 2010, 784-787.

Wang, H., Zhang, S. H., Yin, M. W. And E, N. (2008). Discussion of China water power exploitation strategy under the challenge of energy and environment safety. Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/ Journal of Tianjin University Science and Technology, **41,** 1062-1067.

Watanabe, C. (1972). Industrial-ecology: introduction of ecology into industrial policy. Tokyo: Ministry of International Trade and Industry (MITI).

Xu, J., Kang, J., Shao, L. And Zhao, T. (2015). System dynamic modelling of industrial growth and landscape ecology in China. Journal of Environmental Management, **161,** 92-105.