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Integrating ecological impact indicators into economic restructuring decisions

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ABSTRACT

Establishing a foundation for policy-making to address sustainable development needs multiple tools and integrating sets of ecological, social and economic indicators into development planning. What is consider in literature as a study gap is, how to integrate the ecological impact criteria into economic development decisions. This is important especially in the context of the restructuring of economic structures in response to natural resource constraints such as water, as well as countries' commitments to reduce greenhouse gas emissions (GHGs). To this end, we used an integrated mathematical programming and environmentally-adjusted input-output methodology. The results showed in terms of stimulation to the economic growth the role of industrial activities comparing to agriculture and services sectors is more prominent in the economy so that Food and beverages and the Communications equipment sectors have the highest forward and backward linkages, respectively. In terms of water use results are different in a large extent so that the Crude petroleum and natural gas and mining industries as well as services sector have higher priority. Highest water footprint belongs to agricultural sub-sectors that consume more than 90 percent of the country's water resources. Highest CO_2 footprint among different economic activities belongs to the transportation, industrial activities and Livestock sector. The results of integrated ranking of economic sectors including the weight of each of the three objectives (maximizing production value, minimizing CO_2 emission and water consumption) based on policy makers opinions showed that generally agricultural sub-sectors activities have lower position compared to the industrial and service sectors. This result is unlike the policy orientations of development planning in the past which agricultural sector was considered as a key sector of development in Iran. Based on our findings, to achieve a sustainable economic structure a trade-off is needed between different objectives and the emphasis should be on the development of sectors which have higher economic multipliers while having lower water and CO_2 emission footprints.

1. Introduction

In the past, the prevailing attitude in planning development programs were toward prioritizing economic growth based on income and wealth, and less attention was paid to natural resources restrictions and environmental damages. In such a framework, any economic sector which is capable of making more value added per one unit investment through backward and forward linkages is known as a key sector for stimulation of economic growth (Hirschman, 1958; Aroca, 2001; Lenzen, 2001; Lenzen and Murray, 2003). However, achieving significant economic growth has led to destroying the environment, over exploitation of natural ecosystems capacity and excessive pressure on limited natural resources such as water. This idea nowadays is not justifiable considering the limitation of natural resources (especially water), environmental crises (e.g. greenhouse gases emission, water and soil pollution and etc.) and under the principles of sustainable development that has changed development directions toward green growth patterns (Bekchanove et al., 2012). Sustainable economic development needs integrating economic and ecological indicators - in establishing a platform for policy-making and better decision-making. Integration of economic and ecological indicators into strategic national livelihood and welfare plans enhances sustainable economic development through improved efficiencies and comparative advantages when moving toward green economy (Ekins, 2000).

A green economy is not only based on increasing energy efficiency, but also on increasing resource efficiency in terms of land and water

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(UN, 2009; European Commission, 2009; OECD, 2011; World Bank, 2012). In this approach, it is essential to make strategies and patterns based on different economic, social and ecological criteria. In such a paradigm, the direction of economic development decisions is not just toward stimulating economic growth (backward and forward linkages), but also integrating social (e.g. employment multiplier) and ecological (e.g. water and CO_2 footprint) indicators. Shifting to such a paradigm, is particularly necessary and more critical in countries which are located in arid and semi-arid regions of the world. It is of high importance that countries put greater emphasis on higher value-added sectors while minimizing water use and CO_2 emission, to avoid the associated risks with environmental degradation and economic crises in future.

Globally many researches have been conducted to identify key sectors and prioritize allocation of investment to economic sectors in order to formulate economic development strategies (Albqami, 2004; Miller and Blair, 2009; Atan and Arslanturk, 2012; Rúa and Lechon, 2016). These studies are mainly conducted by economists based on the Leontief input-output model. In these studies, inter-sectoral relationships are calculated in terms of monetary units and determine key economic sectors based on backward and forward multiplier factors. Investment in key sector can effectively lead to overall economic development. As stated above, in these models emphasis is usually on growth impulses, which is only one element of sustainable development principles, and therefore the ecological and environmental aspects of this growth are not taken into account in determining development strategies.

On the other hand, the literature on the definition and quantification of ecological footprints (land use, water consumption, energy consumption and CO_2 emissions) has been widely developed in recent years (Wiedmann et al., 2006; Wiedmann, 2009; Salvo et al., 2015; Chapagain and Hoekstra, 2011; Lee, 2015; Reynolds et al., 2015). The main purpose of these studies is generally to estimate the direct and indirect effects of production and consumption activities, the environmental consequences of global trade, the identification of sectors with highest ecological footprint, and determination of the share of consumers and exporters in the ecological footprint. Using input-output models (IO models) as a top-down approach is one of the practical ways to follow the ecological footprints and the pressure that human activities put on environment. Leontief input-output model (Leontief, 1952), which is basically a monetary model and is based on the theory of general equilibrium has been used as an appropriate method for estimating the inter-sectoral economy linkage and the identification of key sectors for formulating development strategies (Leontief, 1970; Leontief, 1974, 1977; Lenzen, 2003; Blackhurst et al., 2010; Zhao et al., 2010). In general, such monetary input-output models build a perspective in economic exchanges between various sectors of the economy including final demand. These models use environmental flows for each sector, such as energy use intensity, pollution emission, natural resources consumption and other external effects. Several studies of these models have been employed for inter-sectoral environmental flow analysis to identify sectors that require high footprints of water (Hoekstra and Chapagain, 2006; Hoekstra and Mekonnen, 2012; Deng et al., 2015; Wang et al., 2016), ecology (Bicknell, et al., 1998; Wiedmann, et al., 2006), CO_2 (Peters and Hertwich, 2008; Wiedmann, 2009; Minx et al., 2009; Davis and Caldeira, 2010; Davis, et al., 2011) and biodiversity/wildlife (Lenzen et al., 2012; Kitzes, 2012). To be more specific, Ali et al. (2017) focused on the determination of Italian carbon and water footprints, to explain how the human activities affect the environment, through employing multiregional and multi-industry IO models. Galli et al. (2012) investigated the integration of ecological, carbon and water footprints into a “Footprint Family” and tried to track human pressure on the planet. A description of the research question, rationale and methodology of the ecological, carbon and water footprints is first provided. Similarities and differences among the three indicators are then highlighted to show how they overlap, interact, and complement each other.

Table 1
Structure of an input-out model.

	Production sectors $j = 1,2,\ldots,N$		Final demand (Y)		Total input (X)
			Domestic	Export	
Production sectors $j = 1,2,\ldots,N$	Z_{11}…	Z_{1n}	d	e	
Value added (V)	Z_{n1}…	Z_{nn}			
Import (m)					
Total input (X)					

The purpose of this study is to compare and classify sustainable development potential of different economic sectors according to the economic impacts (backward and forward linkages) and ecological effects (water and CO_2 footprints) and integrating them into economic restructuring decisions. An environmental IO model was developed and a sustainable economic structure for Iran was modeled based on the principles of ecological economics. The novelty of the present study is the integration of ecological and economic criteria in an integrated mathematical programming and IO modeling framework.

2. Materials and methods

2.1. The structure of standard input-output model (IO model)

IO model was initially introduced by Leontief (1936). Basis of this model is the mutual relations of production and exchange of material among economic sectors. The flows of goods and services between different sectors are described in terms of monetary units (Wang et al., 2009). Table 1 shows the structure of a standard IO model. In this table, every row shows how much of each sector's production is used in other sectors as intermediate input and final demand. In contrast, every column of the table shows that each sector is using how much of other sector's production as intermediate input for their production.

The overall structure of the model is based on a simple balance of monetary flows (Eq. (1)):

$$[I-A]X = Y \rightarrow X = [I-A]^{-1}Y \quad (1)$$

Where I is an N× N identity matrix, I-A is Leontief matrix, $[I-A]^{-1}$is Leontief inverse matrix, (X) is total input and (Y) is final demand. If we assume$[I-A]^{-1} = B$, therefore elements in the ith column and jth row of IO table (b_{ij}) represents the total direct and indirect production of sector i for each unit increase in final demand of sector j. Matrix form of equation 1 is an IO model that is derived from the demand side and shows production relationship of different economic sectors when the final demand or its components is changing. In other words, X= $[I-A]^{-1}$ describes the structure of the interdependence between sectors based on production. The linkage between the various economic sectors in Table 1 gives us the possibility of calculating the backward (power of dispersion; Eq. (2)) and forward (sensitivity of dispersion; Eq. (3)) linkages and therefore it is possible to identify the key sectors and to evaluate the role of different sectors in the economy (Rasmussen, 1956; Hirschman, 1958). As a result, growth impulses originating from any sectors can affect other supplying sectors (backward linkage) or other using sectors (forward linkage) (Rasmussen, 1956; Hirschman, 1958).

$$U_{.j} = \frac{\frac{\sum_{i=1} b_{ij}}{N}}{\frac{\sum_{ij} b_{ij}}{N^2}} \quad (2)$$

Where (b_{ij}) is the elements of Leontief inverse matrix in demand-driven form as mentioned in Eq. (1).