Zentrum für Entwicklungsforschung
Center for Development Research
University of Bonn

ZEF-Discussion Papers on Development Policy No. 167

Maksud Bekchanov, Anik Bhaduri, Manfred Lenzen and John P.A. Lamers

The role of virtual water for sustainable economic restructuring: evidence from Uzbekistan, Central Asia

Bonn, June 2012

Maksud Bekchanov, Anik Bhaduri, Manfred Lenzen and John P.A. Lamers, The role of virtual water for sustainable economic restructuring: evidence from Uzbekistan, Central Asia, ZEF- Discussion Papers on Development Policy No. 167, Center for Development Research, Bonn, June 2012, pp. 34.

ISSN: 1436-9931

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Straße 3
D – 53113 Bonn
Germany
Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
www.zef.de

The authors:
Maksud Bekchanov, Center for Development Research (ZEF). Contact: maksud@uni-bonn.de
Anik Bhaduri, Center for Development Research (ZEF). Contact: abhaduri@uni-bonn.de
Manfred Lenzen, Center for Development Research (ZEF) and School of Physics, The University of Sydney. Contact: manni@physics.usyd.edu.au
John P.A. Lamers, Center for Development Research (ZEF). Contact: j.lamers@zef.uznet.net

Acknowledgments

This work was partly funded by the Bundesministeriums für Bildung und Forschung and the Australian Academy of Science under their joint Australia-Germany Researcher Mobility Call 2010-2011. The authors thank for Dr. Arnim Kuhn (ILR, Bonn University) for instructive comments to improve the paper.

Abstract

Increases in water demand due to population growth, industrial development and urbanization necessitate economically efficient use of water resources worldwide. This is particularly true in the dryland zones of the world relying on irrigated agriculture for economic development such as in Uzbekistan, Central Asia. Due to ill-managed water resources and the dominance of high water intensive crops, water use efficiency in the region is very low. This challenges Uzbekistan to modernize its agricultural sectors and develop its industrial sectors guided by the principles of a "green economy", which are the basis for sustainable growth. Therefore, this study aims to prioritize economic sectors according to their sustainable growth potential. To this end, we employ a national input-output model to estimate economic backward and forward linkage measures and virtual water contents across the sectors. Our results indicate that developing agro-processing industries and the livestock sector rather than relying on the production of raw agricultural commodities such as cotton, wheat, and rice provides more sustainable economic development in Uzbekistan. However, to exploit these comparative advantages, the necessary market infrastructure and institutions as well as an increased control over wastewaters would need to be implemented.

Keywords: water productivity, input-output model, virtual water content, backward linkage index, forward linkage index, Aral Sea Basin

Introduction

Integration of economic and ecological indicators into strategic national livelihood and welfare plans enhances sustainable economic development through improved efficiencies and exploiting comparative advantages for reaching a "green growth" guided economy (Ekins, 2000). A green economy is based not only on increasing energy efficiency, but also resource efficiency in terms of land and water (UN, 2009). Increases in water demand due to population growth, urbanization, and industrial development often induce decision-makers to allocate limited water resources to selected key sectors for sustainable growth. Such allocation decisions are challenging especially for countries in dryland regions (Rosegrant *et al.*, 2002). Given that these countries cover about 40% of the global area and host about one third of the present world population (Millennium Ecosystem Assessment, 2005), water resource management is a problem of global significance.

Although only relatively smaller areas within the dryland regions have been made suitable for irrigated crop production, they are vital for livelihood, security and welfare, as is demonstrated in the irrigated areas of Uzbekistan, Central Asia. During the last four to five decades of the Soviet rule, the irrigated areas in Uzbekistan expanded to more than 4 Million ha (Mha) (FAO, 2000; Roll *et al.*, 2006), while virtual water consumption tripled to more than 62 km^3 per annum of which about 90% is used for irrigated agriculture (Orlovsky *et al.*, 2000). Due to excessive water use and enormous water wastage in irrigation systems, land degradation and water insecurity has become a grave concern with implications for livelihood and environmental health in Uzbekistan (Rudenko *et al.*, 2012; Glantz, 2009). Such ecological concerns are exacerbated given declining water supply coupled with an increase in water demand due to population growth and industrial development. Hence, development policies in this country and in many other dryland regions need to consider not only economic indicators but also ecological factors with at least equal importance.

Water issues in Uzbekistan have a two-sided nature: surplus and scarcity. Water scarcity is common in the vegetation period particularly in the dry years due to low volume of the water releases from the upstream reservoirs. Water stored in these reservoirs is released for hydropower generation during the winter period, and causes floods downstream since there is little irrigation demand for water during this time of the year. Our study compares different sectors and determines the key sectors with higher water productivity for sustainable economic restructuring under such circumstances. The findings of the study are relevant not only to Uzbekistan, but also to the four other countries in Central Asia - Kazakhstan, Kyrgyzstan, Tajikistan, and Turkmenistan – and to countries in other dryland regions.

Identifying key sectors for sustainable economic development ("green economy") is a central question confronting regional development agencies who seek information for determining efficient allocation of investments among economic sectors to promote the sectors with the potential of higher-than-average economic growth impact, particularly in transition economies. The sectoral structure of an economy substantially affects the level of economic development as previously postulated in the three-sector hypothesis (Clark, 1940; Fourastie, 1949). It is thought, for instance, that the share of primary sectors such as agriculture and mining industries in Gross Domestic Product (GDP) shrinks, while the share of secondary and tertiary industries increases in parallel to welfare improvement. However, a heterogeneous distribution of natural resources, labor forces, environmental-climatic conditions, technological factors, and trade interrelationships across countries often restricts an anticipated commodity production specialization. Determining key sectors for economic growth in dryland areas, typified by a strong dependence on water, can be supported by estimating direct and indirect water use (virtual water use) requirements of all sectors in addition to the commonly used economic linkage indicators (Lenzen, 2003). Although marginal productivity (opportunity cost) is decisive in economic decisions over allocating of scarce resources rather than average water productivity measures such as virtual water (ANWC, 2008), marginal and average water productivities are the same when linear relationship between water use and production are assumed. Therefore, water allocation decisions can be based on average water productivity values under this assumption. Thus, our results are only valid under the assumption of linear relationship between water and economic output.

The input-output model of Leontief (1951) is acknowledged as an appropriate method for estimating economic intersectoral linkages by sectors as it allows analyzing the interdependence of sectors in monetary units (Hirschman, 1958; Bharadwaj, 1966; Hazari, 1970; Jones, 1976). The unique structural feature of input-output models also provides an opportunity to integrate the use of water and other resources (Lenzen, 2003). Input-output models of resource chains have some advantages over the common bottom-up approach of estimating virtual water content (Chapagain and Hoekstra, 2003; Chapagain and Hoekstra, 2004; Chapagain and Hoekstra, 2007; Mekonnen and Hoekstra, 2010). First, the conventional approach of measuring the virtual water content as a physical water requirement per physical output is limited and inadequate if one intends to compare the commodities of different sectors. For example, the comparison of the virtual water content of one kg of meat to one kg of wheat neglects the fact that these two commodities have different economic and nutritional values. However, since the financial and economic values of different commodities can be compared, estimating and comparing water use per economic value of the commodity are more relevant than water use per physical unit. Second, the bottom-up approach only partially covers virtual water use (Feng *et al.*, 2011a; Feng *et al.*, 2011b, Van Oel *et al.*, 2009). For instance, the bottom-up approach based virtual water content of raw cotton is indicative of the amount of water consumed, but this approach has limitations in the sense that it does not include information on how much water is used to produce inputs for cotton production such as fertilizers, tractors, and energy carriers used during field operations. Water requirements in upstream sectors are especially relevant in cases where intermediate inputs into production are produced domestically. A top-down approach, employing input-output models, allows virtual water calculations to incorporate not only the water use by all intermediate inputs, but also water use throughout all supply chains related to these intermediate inputs (Lenzen, 2009; Duarte and Yang, 2011). Thus, the mainstream bottom-up approach of calculating virtual water tends to systematically underestimate the “real” virtual water use of commodities.

A key sector is defined as one that during its growth will promote an above average expansion in other sectors. Input-output models are applied to identify such economic key sectors for the formulation of economic development strategies (Rasmussen, 1956; Hirschman, 1958). Growth impulses originating from any sector can propagate to other supplying sectors (backward linkage) or to other using sectors (forward linkage) (Rasmussen, 1956; Hirschman, 1958). Considering sectors with corresponding higher-than-average backward and forward linkages as “key sectors”, Hirschmann (1958) postulates that investments in such “key sectors” are efficient to induce overall economic development.

Chenery and Watanabe (1958) use the column and raw sums of the technical production coefficients matrix as backward and forward linkages respectively. In contrast, Rasmussen (1956) and Hirschmann (1958) suggest using the column and raw sums of the Leontief inverse matrix as backward and forward linkages respectively since the latter covers full linkage relationships. Hazari (1970) introduces a weighting scheme for backward and forward linkage measures, thus considering the relative importance of each sector in accordance with its final demand or value added. Another approach for estimating the importance of any sector to the economy is the hypothetical extraction method (HEM). The latter approach is characterized by hypothetical elimination of a sector, and followed by estimation of the impact on multipliers (Strassert, 1968). Different forms of the hypothetical extraction method are proposed by Cella (1984), Hewings (1982), and Sonis et al. (1995). A more recent linkage measure is proposed by Oosterhaven and Stelder (2002), in which the output generated in all sectors as a response to final demand of a certain sector is normalized for the output generated in this sector. Despite substantial improvements and expansion on input-output linkage analysis, all alternative approaches to measure intersectoral relationships have advantages and disadvantages and they should be considered as complementary rather than exclusive (Lenzen, 2003). However, the approach introduced by Rasmussen (1956) and Hirschman (1958) is in common use by practitioners and considered as a standard way of estimating intersectoral linkages (Midmore *et al.*, 2006).

Beyers (1976) and Jones (1976) show several shortcomings of the Leontief inverse model to measure forward linkages. For instance, a raw sum of Leontief's inverse matrix is 'the result of demand generated by user's backward linkage' (Jones, 1976), and thus, it cannot be used to measure forward linkages. Therefore, these and other authors (Miller and Lahr, 2001) recommend the Ghosh inverse matrix (1958) as the only reasonable candidate for calculating forward linkage indices. However, the Ghosh model is heavily criticized for its implausibility in capturing causal relationships between primary inputs and economic growth (Oosterhaven, 1988; Oosterhaven, 1989; Oosterhaven, 1996; de Mesnard, 2009). Considering these above works and Dietzenbacher (1997), a Ghosh model can be used only as a price model which can capture the price effects without quantity effects. Consequently, the Ghosh inverse model can only be used as a static and descriptive tool to measure forward linkages which are interpreted as the amount of output required to absorb primary inputs (Lenzen, 2003).

Input-output based analysis has been used also to address environmental concerns with the incorporation of energy and water components into environmentally extended input-output tables. Several studies have employed environmentally extended input-output models to analyze the intersectoral water flows and thus identify economic sectors that require large amounts of direct and indirect water use (Lenzen and Foran, 2001; Lenzen, 2003; Velazquez, 2006; Dietzenbacher and Velázquez, 2007; Zhao *et al.*, 2009; Smajgl and Liagre 2010; Lenzen, 2009; Feng *et al.*, 2011). Gallego and Lenzen (2005) apply backward and forward linkage-based virtual water contents to determine a consumers' and workers/investors' responsibility to water consumption according to their final demand and primary inputs use respectively. Non-causal interpretation of forward linkages discussed above should be also applied to environmentally extended input-output models (Gallego and Lenzen, 2005).

Input-output approaches are ideally suited to integrate incommensurable physical indicators into one unified and consistent framework (Vardon *et al*., 2006). For example, in their Triple Bottom Line analysis of the Australian economy, Foran *et al.* (2005) contrast and compare virtual water with other indicators of sustainable development, notably greenhouse gas emissions, land disturbance, employment, family income, and government revenue. Indeed, the United Nations recognize the need for such integrated economic-environmental framework in their System of Environmental-Economic accounting for Water (UNSD, 2011).

This study aims at applying the environmentally extended input-output model to the case study country - Uzbekistan by combining direct and indirect virtual water use as an environmental sustainability factor with economic linkage indicators. The approach introduced by Rasmussen (1956) and Hirschman (1958) is followed in this paper for assessing intersectoral linkage measures due to its simplicity. Moreover, as previously discussed, this approach has remained as a standard way of calculating linkage indices on the basis of input-output tables. The Gosh model is used for estimating forward linkages considering irrelevance of the Leontief model for this purpose. The objectives of the analyses are to compare and classify economic sectors according to water use content and economic linkages index, and determine how to adjust the economic restructuring using this approach.

Characteristics of the study region

Economy and agriculture in Uzbekistan

During the Soviet Union (SU) era, Uzbekistan was a raw commodity supplier to the Union and the national economy was specialized in cotton production consequently determining high share of the agriculture in GDP. However, after independence in 1991, the GDP structure changed significantly due to the policies introduced to stimulate industrialization as well as extreme increase in parity between the prices for industrial and agricultural commodities.

In the early 1990s, the agricultural sector contributed to about one third of GDP (Figure 1). However, this share decreased to 24% by 2007 (UzStat, 2008) although in absolute values the share of the sector increased (Sutton *et al.*, 2008). During 1995 and 2007, the share of industry increased from 20% to 27% (Fig. 1). Concurrently, the share of the transport and communications and trade sectors went up from 8% to 12% and from 6% to 10%, respectively. The national GDP at factor prices had an average growth rate of 4.9% in this period, with a growth rate of 3.6 % per capita.

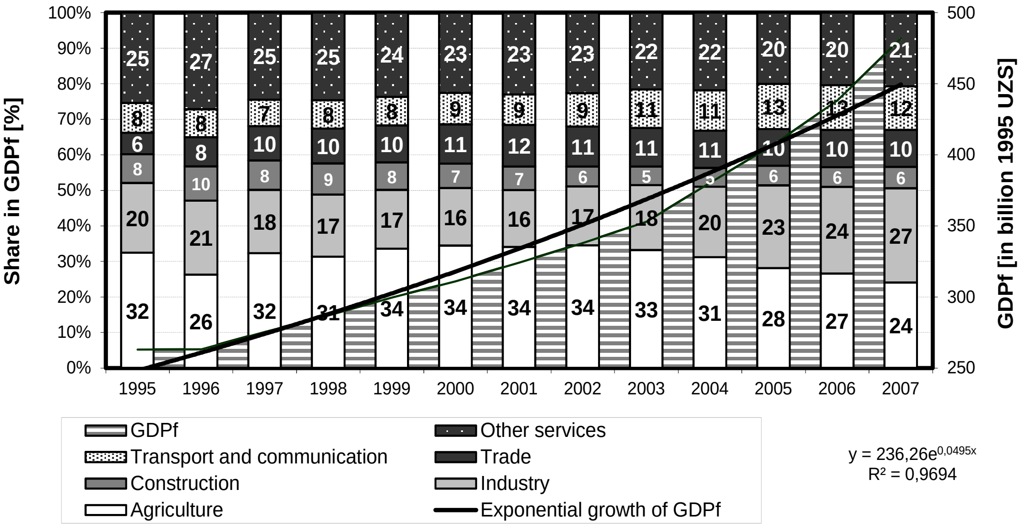


Fig. 1 Levels and sectoral structures of GDP at factor prices (GDPf). Average exchange rate for 2005: 1,128 UZS =1 US$**.** Source: UzStat 2008, authors' presentation

Before the 1990s, Uzbekistan produced more than 60% of the total cotton fiber ("the white gold") in the SU that was mainly exported to the Ukraine and Russia. Reforms initiated after

1991 to facilitate a transition towards a market-oriented economy impacted on the structure of the export commodities. The share of cotton in total export revenues decreased from 28% to 10% between 2000 and 2008 (Figure 2). In the pre-independence period, about 60% of the total petroleum consumption was imported from other SU countries. However, since independence Uzbekistan at first became self-sufficient in energy resources and gradually turned into a net exporter by developing its oil and gas mining resources that had previously been exploited marginally. The share of oil and gas commodities in total exports increased from 10% to 25% whilst the export volumes increased from 3.2 to 11.6 billion USD. The share of the metallurgy in total exports did not exceed 13% in the study period (UzStat, 2008). However, other studies indicate higher share of metallurgy varying between 25% (in 2001; Müller, 2006) and 30% (in 2005; UNDP, 2006 and CEEP, 2006).

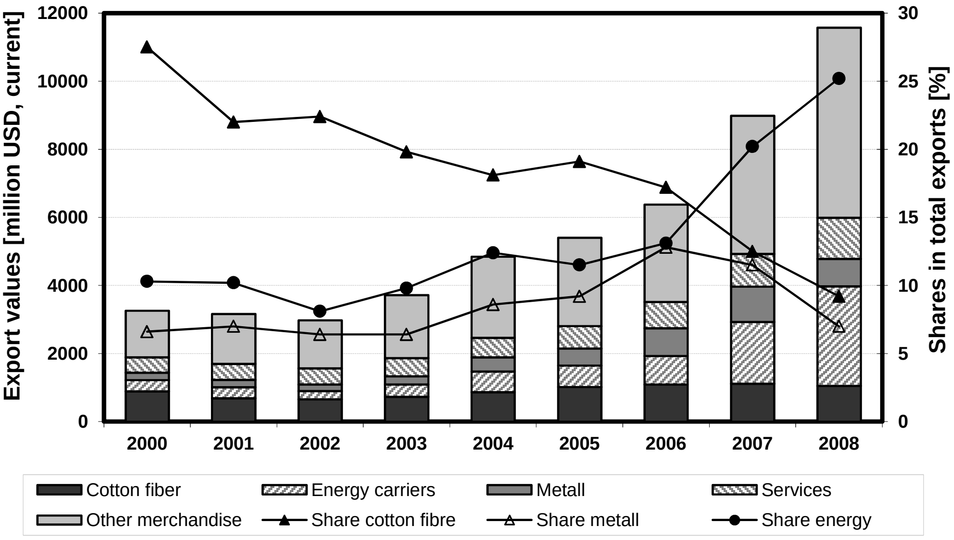


Fig. 2 The dynamics of the export structure over time in Uzbekistan. Source: UzStat 2008, authors' presentation

Since industrialization and modernization of the different sectors were prioritized between 2000 and 2008, export revenues were often used to import capital goods (Figure 3). As a consequence, the share of machinery in the total imports increased from 36% to 53%. In parallel, the share of food commodities in overall imports decreased from 12 to 8% despite the slight increase in the absolute volume (Figure 3). Guided by the grain and energy self-sufficiency (import substitution) policies and strategies to decrease the dependence on the cotton export revenues, Uzbekistan managed to become less vulnerable to the dynamics of the *"resource curse*" (McKinley, 2008).

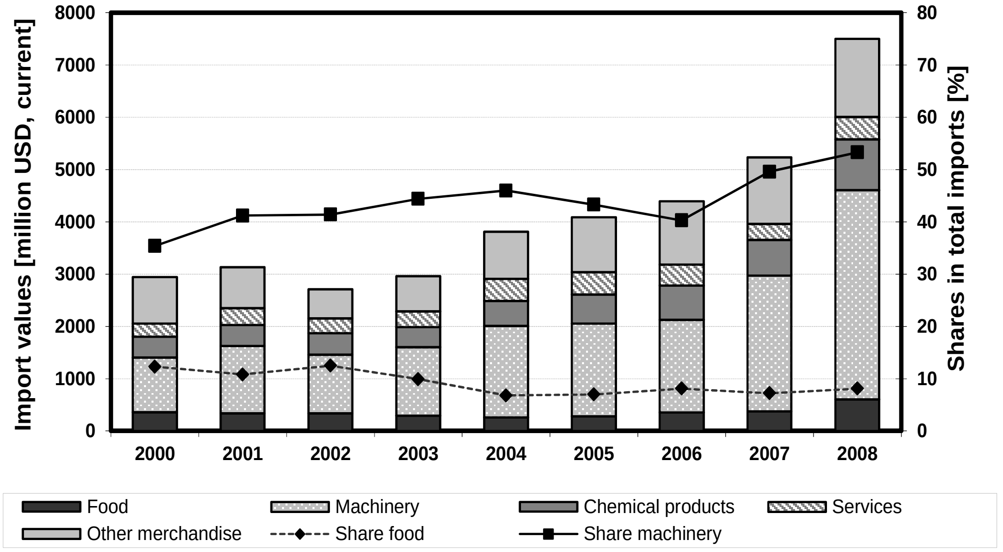


Fig. 3 The dynamics of the import structure in Uzbekistan over 2000-2008. Source: UzStat 2008, authors' presentation

Water use by sectors

In spite of its decreased share in GDP, agriculture remained an important sector in the economy of Uzbekistan; agriculture, for instance, still accounts for more than 60% of the overall employment, and the share of cotton still exceeds 40% of the total cropped area. Consequently, agriculture, with a share of more than 90% (Figure 4), is still the main consumer of the total annual water resources, which amounts to about 62 km^3 annually, most of it originating from neighboring countries (Sutton *et al.*, 2008).

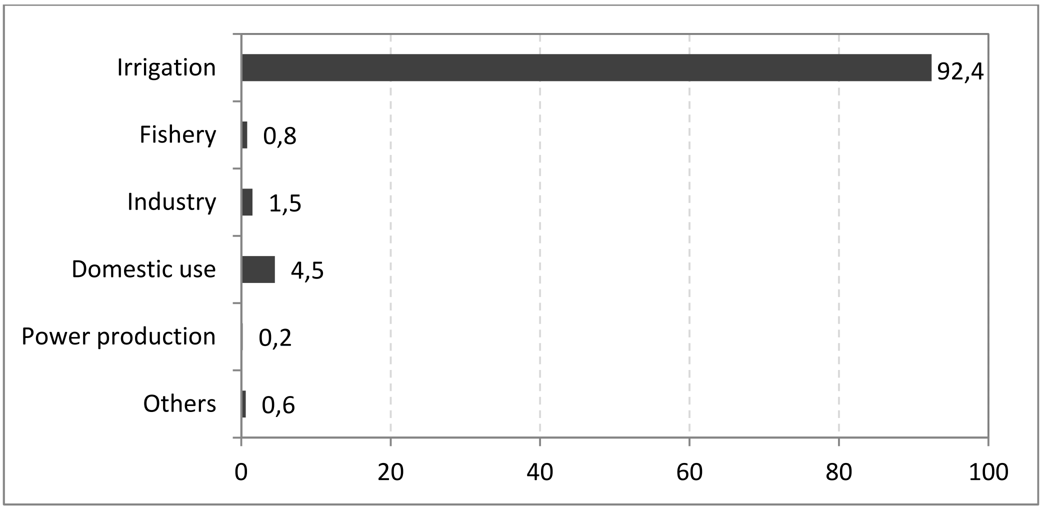


Fig. 4 Share of economic sectors in total water use in Uzbekistan (%). Source: UNDP 2007

Data sources and methodology

Estimation of the Uzbek input-output table

During the SU era, government statistical organizations were entrusted with the development of national and regional input-output tables (IOTs). After independence, those IOTs were not developed and reported further by this organization. Coming to 2001, to calibrate a computable general equilibrium (CGE) model, Müller (2006) developed national IOT with twenty sectors for 2001. More recent IOT of Uzbekistan include an IOT developed in 2005 by the researchers of Center for Efficient Economic Policy (CEEP), Center for Economic Research (CER), Ministry of Economy (MoE) and Colorado University for analyzing national tax policy reforms (UNDP, 2006). However, in this IOT, only the shares of each entry in the column totals are reported rather than the absolute values. Since this IOT-2005 is the most recent complete database, we use it as the basis for the calculations of IOT values despite its limitations.

In this study, the absolute values of IOT entries are evaluated based on relative values given in IOT-2005 and the secondary data on production values, GDP, value added, export-import, and consumption levels by different national and international organizations. For instance, aggregated macroeconomic indicators are obtained from the Asian Development Bank (ADB, 2008) and National Statistical Committee of Uzbekistan (UzStat, 2008). Concurrently, detailed data on GDP, export and import volumes by sectors are obtained from the National Statistical Committee (UzStat, 2008) and the Uzbek Center for Efficient Economic Policy (CEEP, 2006). Since the IOT-2005 has a single aggregated account for agriculture, considering that most of the water resources are used in the agricultural sector and this sector plays a pivotal role in the economy, agriculture and agricultural processing sectors are disaggregated. This disaggregation is based on the proportional shares borrowed from the IOT by Müller (2006). At the end, the obtained unbalanced national IOT for twenty sectors for 2005 is balanced using the maximum cross entropy approach (Golan *et al.*, 1996; Müller, 2006).

Values of the input-model components are estimated in Uzbek soum. Since official exchange rates for Uzbek soum (UZS) compared to USD varied between 1080 and 1180 UZS USD^{-1}

throughout the year 2005 (CEEP, 2006), an estimated average exchange rate of 1128 UZS USD^{-1} is used for conversion into USD.

Estimation of total direct water use by sectors

The aggregated water use data (UNDP, 2007; Figure 4) are used to estimate water consumption by subsectors of the agrarian and industrial sectors considering existing water consumption norms either per number of livestock, or per hectare of crop land, or per one unit of commodity output. For instance, water consumption in the livestock sector is estimated based on the number of each type of livestock (cattle, sheep and goats, pigs, horses, and poultry) as derived from official statistics (UzStat, 2008) and their annual water consumption norms (CRIIWRM, 1980). To estimate crop water use, first, we estimate recommended water consumption for each agricultural sub-sector on the basis of information on crop land area (UzStat, 2008) and recommended water use per ha for each crop (Müller, 2006). Then we calculate the relative shares of each subsector to total recommended agricultural water consumption. Finally, the subsector water uses are derived after multiplying the relative shares with the difference between real total agricultural water use and livestock water consumption.

The same procedure allows estimating water use in the industrial subsectors. Physical production volumes of industrial commodities are obtained from UzStat (2006), whereas water consumption norms per unit of produced commodity from the State Construction Office (1978). The prior water consumption for each industrial subsector is calculated based on the total commodity production and recommended water consumption per unit of produced commodity. Next, the shares of prior water use of each industrial subsector in total recommended industrial water consumption are calculated. These shares are used to estimate the real industrial subsector water use knowing the real total industrial water use.

Leontief model

The intersectoral flows in a given economy are calculated using an input-output system according to Leontief (1951):

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \qquad (1)$$

where x is a *n*x1 vector of total production volumes for each sector, y is a *n*x1 vector of final demand including private and government consumption, investment expenditures, changes in inventories, and exports. $\mathbf{A}$ is a *n*x*n* matrix of technical production coefficients. In this model, with simple transformations, final demand is treated as an exogenous variable which determines the level of total production:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{y} = \mathbf{Ly} \qquad (2)$$

where $\mathbf{I}$ is an *n*x*n* identity matrix and $\mathbf{L}$ is the *n*x*n* Leontief inverse matrix. An element l_{ij} of the Leontief inverse L reflects the total requirements from sector i to provide a unit of the final demand for the commodities of sector j.

Ghosh model

The Ghosh model (Ghosh, 1958) is used to estimate intersectoral allocation of primary and intermediate inputs:

$$\mathbf{x}' = \mathbf{x}'\mathbf{B} + \mathbf{v}' \qquad (3)$$

where $\mathbf{B}$ is a *n*x*n* matrix of allocation coefficients which is calculated as a ratio of intersectoral intermediate inputs to the total inputs (raw sums of input-output table) and v' is a 1x*n* vector of primary factors which includes capital, labor, and imports. The prime symbol ʻ denotes matrix transposition.

Similar to (Eq. 2), with simple transformations, the relationship between the primary factors and the level of total production is obtained:

$$\mathbf{x}' = \mathbf{v}'(\mathbf{I} - \mathbf{B})^{-\mathbf{1}} = \mathbf{v}'\mathbf{G} \qquad (4)$$

where $\mathbf{G}$ is an *n*x*n* Ghosh inverse matrix. An element g_{ij} of the Ghosh matrix $\mathbf{G}$ reflects the total required outputs from sector *j* to absorb a unit of the primary factors of sector i.

The backward and forward linkage indexes

The Leontief inverse matrix (Eq. 2) allows to measure direct and indirect effects of a change in the final demand over production as well as to calculate the backward linkage index (BLI). The BLI of sector j which shows how much sector j influences on the output of all sectors through its purchases (input uses) is calculated following the approach by Rasmussen (1956) and Hirschman (1958):

$$BLI_j = (L_{*j}/n)/L^{*} \qquad (5)$$

where L^{*} is the mean over all elements of the Leontief inverse L (Eq. 2) and L_{*j} is the associated column sum of elements of the matrix $\mathbf{L}$ for sector j.

Considering the relevance of the Ghosh model (Eq. 4) to calculate the forward linkage index (FLI) (Beyers, 1976; Jones, 1976), FLI of the sector i which indicates how much sector i influences on the output of all sectors through its sales (output supplies) is elaborated based on the Gosh model instead of the Leontief model, as follows:

$$FLI_i = (G_{i*}/n)/G^{*} \qquad (6)$$

where G^{*} is the average value of all elements of the Ghosh inverse matrix $\mathbf{G}$ (Eq. 4) and G_{i*} is the associated raw sum of elements of the matrix $\mathbf{G}$ for sector i.

BLIs and FLIs are useful compare sectors according to their influence and dependence on the remaining sectors and through this on the overall economy. BLI_j >1 indicates strong backward linkages of sector j which means that a unit increase in the final demand of sector j would result in greater-than-average increase in total economic output. In parallel, FLI_i >1 shows strong forward linkages of sector i meaning that a unit increase in primary inputs of sector i would require greater-than-average increase in total economic output. If both conditions, BLI_j >1 and FLI_i >1, are fulfilled for any sector, this sector is considered as a key sector which exhibits both greater-than-average influence and dependence on the remaining sectors (Lenzen, 2001).

Direct and indirect water uses

Integration of virtual water content of commodities with BLIs and FLIs would allow for more rational decisions on economic restructuring as water is a main restricting factor to the economic development of countries in dryland regions including Uzbekistan. To estimate virtual water contents, direct water input coefficients (dw_j) are estimated initially as the ratio of total sector water use (W_j) to the total production volume of a given sector j ($\mathrm{Q_j}$):

$$dw_j = W_j/Q_j \qquad (7)$$

Based on these direct water use coefficients and Leontief inverse matrix elements, virtual water multipliers (VWMs, vw_j), in other words backward-linkage-based full water content, which indicates the total (both direct and indirect) amount of virtual water that is required to produce a unit of final demand in sector j, are calculated as:

$$vw_j = \sum_i dw_i l_{ij} \qquad (8)$$

Similarly, forward linkage based full water content which indicates the total (both direct and indirect) amount of virtual water that is required to absorb a unit of primary factors in sector i, are calculated as:

$$vw_i^G = \sum_j dw_j g_{ij} \tag{9}$$

k-means method of classifying economic sectors

Since ordering sectors is complex when multiple criteria is considered, we preferred to group them into clusters. Economy sectors are classified according to adjusted BLI, FLI, and VWM of each sector. Pre-classification adjusting is needed to make all variable values comparable to each other.

Adjusting of BLI and FLI is conducted relative to their maximum values (BLI_j^{max} and FLI_i^{max} respectively):

$$BLI_j^{adj} = BLI_j / BLI_j^{max} \tag{10}$$

and

$$FLI_i^{adj} = FLI_i / FLI_i^{max} \tag{11}$$

For adjusting a VWM, its minimum value (vw_j^{min}) is divided by each VWM, since lower value of VWM, i.e. lower virtual water use per unit of production, is more favorable:

$$vw_j^{adj} = vw_j^{min} / vw_j \tag{12}$$

Four clusters of the sectors are defined following the simple rule of thumb for determining the number of clusters (Mardia *et al.*, 1979):

$$k \approx \sqrt{n/2} \tag{13}$$

Clusters are expected to comprise sectors which economic impact and environmental sustainability parameters are as close as possible to each other (closest points in multi-dimensional space). Therefore, in order to classify the sectors we use *k*-means clustering method which aims to partition *n* observations into *k* groups in which each observation belongs to the group with the nearest mean (MacQueen, 1967). In mathematical terms, given a set of observations $(x_1, x_2, \ldots, x_n)$, where each observation is a *d*-dimensional real vector, *k*-means clustering aims to partition the *n* observations into *k* sets ($k \leq n$)

$\mathrm{S} = \{\mathrm{S}_1, \mathrm{S}_2, \dots, \mathrm{S}_\mathrm{k}\}$ so as to minimize the sum of within-group deviations around the mean of points (μ_i) in S_i:

$$\sum_{i=1}^{k} \sum_{x_j \in \mathrm{S}_\mathrm{i}} (x_j - \mu_i)^2 \rightarrow min \qquad (14)$$

Calculations related to this classification are conducted using SPSS software.

Sectoral and intersectoral structure of the Uzbekistan economy

The highest intermediate demands by the sectors are observed for the commodities of fossil fuel industry, trade, transport and communications (Table 1). These sectors can be considered metaphorically as the “blood” of the economic “organism” since production and inter-sector commodity exchanges in the economy would not occur without their participation.

Table 1 Input-Output Table (Quadrant II), in billion Uzbek soums (UZS). Average exchange rate for 2005: 1,128 UZS =1 US$

		Intermediate use		**Private consumption**		**Investment expenditures**		**Government expenditures**		**Exports**		**Imports**		**Total output**	
Sectors		**Amount**	**Share[%]**	**Amount**	**Share[%]**	**Amount**	**Share[%]**	**Amount**	**Share[%]**	**Amount**	**Share[%]**	**Amount**	**Share[%]**	**Amount**	**Share[%]**
ACOT20	Cotton	1135	6.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1135	3.5
AGRN20	Grains	310	1.8	438	5.6	0	0.0	200	9.4	0	0.0	63	1.3	886	2.7
ARIC20	Rice	23	0.1	41	0.5	0	0.0	0	0.0	0	0.0	0	0.0	64	0.2
AGAR20	Gardening	67	0.4	447	5.8	0	0.0	0	0.0	77	1.2	0	0.0	592	1.8
AFOD20	Fodder	301	1.7	49	0.6	0	0.0	0	0.0	0	0.0	0	0.0	350	1.1
AOTH20	Other crops	54	0.3	476	6.1	0	0.0	0	0.0	12	0.2	0	0.0	542	1.7
AANM20	Livestock	169	1.0	2600	33.5	60	1.5	0	0.0	0	0.0	0	0.0	2829	8.6
APOWE20	Energy industry	1287	7.3	46	0.6	0	0.0	0	0.0	22	0.4	24	0.5	1332	4.1
AFUEL20	Oil and gas	3192	18.2	114	1.5	0	0.0	0	0.0	712	11.4	102	2.1	3916	11.9
AMETL20	Metallurgy	1025	5.8	0	0.0	0	0.0	0	0.0	1736	27.8	472	9.5	2290	7.0
ACHEM20	Chemical industry	818	4.7	54	0.7	0	0.0	0	0.0	338	5.4	452	9.1	757	2.3
AMAEQ20	Machinery	1390	7.9	132	1.7	1624	39.6	0	0.0	536	8.6	1976	39.8	1706	5.2
ACTPR20	Cotton processing	596	3.4	54	0.7	0	0.0	0	0.0	1375	22.0	0	0.0	2025	6.2
ALGHT20	Light Industry	374	2.1	584	7.5	0	0.0	0	0.0	0	0.0	119	2.4	839	2.6
AFOOD20	Food industry	310	1.8	516	6.7	0	0.0	0	0.0	562	9.0	338	6.8	1050	3.2
AOIND20	Other industries	1281	7.3	363	4.7	0	0.0	0	0.0	180	2.9	520	10.5	1304	4.0
ACON20	Construction	0	0.0	0	0.0	2329	56.8	0	0.0	0	0.0	14	0.3	2314	7.0
ATRD20	Trade	2122	12.1	0	0.0	0	0.0	0	0.0	0	0.0	231	4.6	1891	5.8
ATCM20	Transport and communication	2105	12.0	732	9.4	0	0.0	192	9.0	611	9.8	526	10.6	3113	9.5
AOTS20	Other services	1012	5.8	1112	14.3	89	2.2	1733	81.5	77	1.2	121	2.4	3902	11.9
TOT	Total	17572	100	7758	100	4101	100	2125	100	6239	100	4958	100	32837	100

Source: Authors' estimations

Table 2 Input-Output Table (Quadrants I and III), in billion Uzbek soums (UZS). Sectoral abbreviations are defined in Table 1. Average exchange rate for 2005: 1,128 UZS =1 US$

	ACOT20	AGRN20	ARIC20	AGAR20	AFOD20	AOTH20	AANM20	APOWE20	AFUEL20	AMETL20	ACHEM20	AMAEQ20	ACTPR20	ALGHT20	AFOOD20	AOIND20	ACON20	ATRD20	ATCM20	AOTS20
ACOT20	0	0	0	0	0	0	0	0	0	0	0	0	1135	0	0	0	0	0	0	0
AGRN20	0	18	0	0	0	0	79	0	0	0	0	0	0	0	208	0	0	2	0	3
ARIC20	0	0	2	0	0	0	0	0	0	0	0	0	0	0	21	0	0	1	0	1
AGAR20	0	0	0	26	0	0	0	0	0	0	0	0	0	0	33	0	0	4	0	5
AFOD20	0	0	0	0	15	0	287	0	0	0	0	0	0	0	0	0	0	0	0	0
AOTH20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	0	0	0	0	0
AANM20	0	0	0	0	0	0	34	0	0	0	0	0	0	34	99	0	0	0	0	2
APOWE20	27	26	0	17	0	0	81	56	170	161	172	44	54	9	10	112	25	50	140	132
AFUEL20	134	144	0	96	58	0	235	724	743	135	49	30	0	0	9	108	79	34	313	302
AMETL20	0	0	0	0	0	0	0	0	0	652	88	162	0	0	0	37	86	0	0	0
ACHEM20	61	62	5	41	21	43	4	26	18	76	159	24	11	38	6	82	58	1	38	44
AMAEQ20	7	9	1	6	3	8	16	32	32	167	18	652	25	9	3	56	76	7	146	116
ACTPR20	19	0	0	0	0	0	8	0	0	0	0	0	404	110	41	14	0	0	0	0
ALGHT20	0	0	0	0	0	0	3	0	0	7	3	9	9	253	83	8	0	0	0	0
AFOOD20	0	0	0	0	0	0	171	0	0	0	0	0	0	0	138	1	0	0	0	0
AOIND20	4	4	0	3	2	0	22	7	18	16	5	18	10	0	3	115	719	67	126	142
ACON20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ATRD20	40	44	3	28	16	25	132	102	170	229	84	297	155	71	76	217	143	0	31	257
ATCM20	5	19	2	15	6	18	54	15	264	26	13	21	25	10	14	100	333	214	606	344
AOTS20	6	17	2	13	6	15	49	22	54	54	6	84	21	17	21	67	36	126	92	302
Labor	275	75	10	130	19	143	381	73	628	166	59	124	44	40	42	56	517	459	978	1493
Capital	556	467	40	216	204	290	1273	274	1819	600	102	241	134	248	190	329	243	927	643	758
Total Output	**1135**	**886**	**64**	**592**	**350**	**542**	**2829**	**1332**	**3916**	**2290**	**757**	**1706**	**2025**	**839**	**1050**	**1304**	**2314**	**1891**	**3113**	**3902**

Source: Authors' estimations

Private consumption consists of mainly products of livestock husbandry. The highest share of the livestock commodities in the private consumption can be explained by high prices for milk, eggs, and meat and the commonality and food security role of livestock husbandry of small-scale households in rural areas (Djanibekov, 2008) where more than 60% of the total population lives. Private consumption expenditures on transport and communications are also high which is evidenced by the recent widespread purchase of cell phones and increased mobility of the population due to seasonal labor migration (Djanibekov, 2008). Concurrently, private consumption of commodities of the light and food industry is also large since these sectors produce commodities for the human basic needs.

Commodities produced by the machinery and construction sectors are considered as investments. Government expenditures are directed to the purchase of the goods from other services such as education, state health care, and governmental bank services whose employers are paid from the governmental budget. As explained earlier, main export revenues are generated through commodities from the sectors of metallurgy, cotton processing, and fuel industry while imported are mainly commodities of the machinery industry.

Intersectoral flows of intermediate input use as well as labor and capital resources (including operating surplus) by sectors are given in Table 2. Agricultural commodities contribute substantially to the intermediate use of cotton and food processing industries. In turn, agricultural activities mostly rely on the commodities from the fossil fuel sector which can be explained by high prices for fuel and extensive agricultural machinery use. The construction sector heavily depends on commodities from the sector of other industries, predominantly construction materials including timber, bricks, and glasses. The most labor intensive sectors turns out to be transport and communication, other services including all state services organizations such as schools, kindergartens, hospitals, banks, etc. Based on this input-output table the technical production and allocation coefficients as well as Leontief and Ghosh inverse matrices are estimated. Leontief and Ghosh inverse matrices are then used to calculate BLIs, FLIs, and VWMs.

Identifying key sectors of the economy

Economic linkage measures indicated through BLIs and FLIs and of ecological impact indicators such as direct and indirect virtual water use are integrated to compare different economic activities and to identify the key sectors. The findings illustrate that industrial sectors have generally higher BLIs compared to those in the agricultural sector. The BLIs for agriculture vary between 0.7 and 1.0 while those in the industrial sector vary between 0.9 and 1.4 (Figure 5). Fruits and vegetables sector has the highest BLI among all agrarian sub-sectors (1.0). BLIs of all industries except oil and gas and machinery sectors are higher than average.

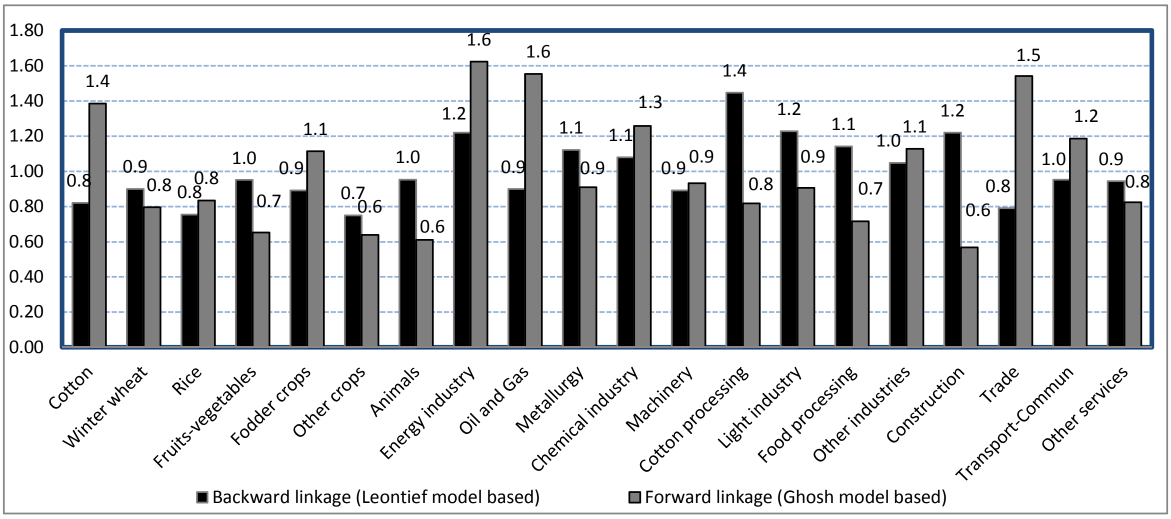


Fig. 5 Estimated backward and forward linkages

Similar to the case of BLIs, FLIs of industrial sectors are also generally higher compared to those in the agricultural sector (Figure 5). The FLIs for all agricultural sub-groups vary between 0.6-1.4 while the FLIs for industrial sub-sectors vary between 0.7-1.6. The FLI for the raw cotton production sector is the highest among all agricultural sub-sectors as the main user of raw cotton commodities – the cotton processing plants - are well developed across the country. With a value of 1.6, the highest FLIs are estimated for the fossil-fuel based industries (oil and gas) and energy sector. The FLIs for the sectors trade and transport and communication, with the values of 1.5 and 1.2 respectively, are higher than the FLIs of most of the agricultural and industrial sectors. In general, the key sectors with a BLI and FLI value of higher than one, are energy, chemical industry, and other industries in construction materials production.

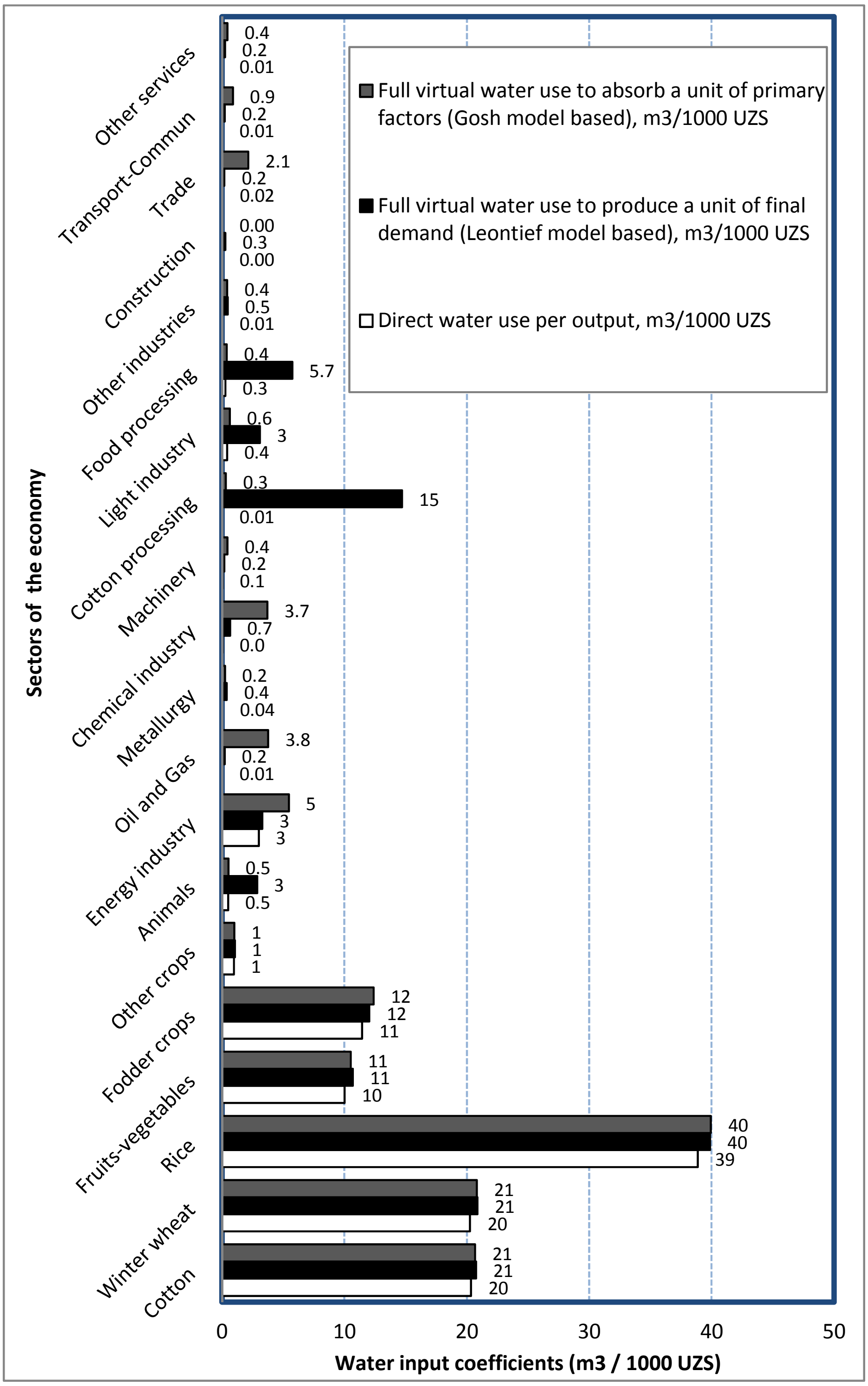


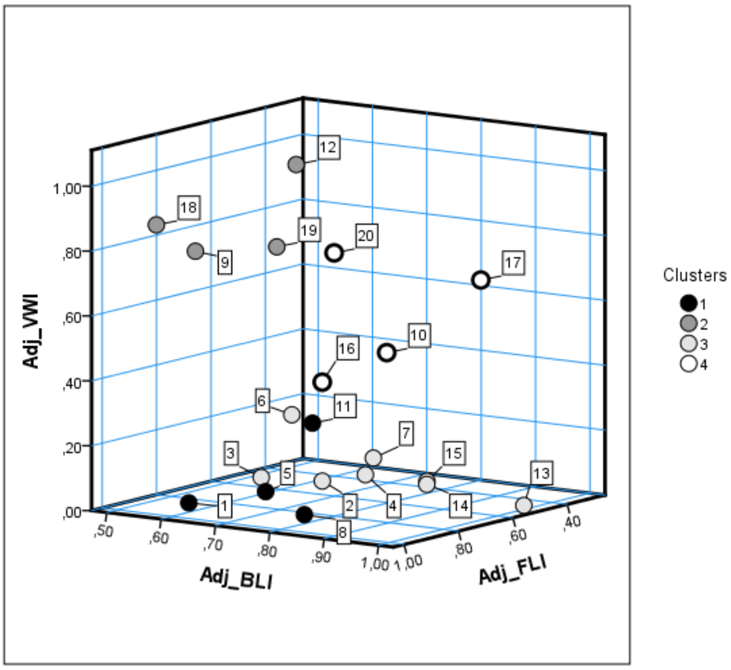
Fig. 6 Virtual water use by sectors of the economy in Uzbekistan. Average exchange rate for 2005: 1,128 UZS =1 US$

The analysis of virtual water content by sector allows comparing these sectors according to the direct and total water consumption requirements for producing any commodity equivalent of 1000 Uzbek soums (UZS) (Figure 6). Comparisons of direct water use coefficients across the sectors show that, in general, agricultural commodities require substantially higher amount of water per 1000 UZS than the commodities of all other sectors. Within the agricultural sector, rice requires the highest amount of water to produce a unit of its economic output - 39 m^3 per 1000 UZS (34.5 m^3 USD^{-1}). To produce cotton and winter-wheat commodity of worth 1000 UZS, about 20 m^3 water (18.0 m^3 USD^{-1}) is required directly. Although physical water requirement per ha for winter wheat is comparatively lower than that for the other crops examined, its direct water use coefficient is most likely influenced also by the low prices for grain imposed by the national administration; whereas this is not the case with the crops other than wheat and cotton. The production of fruits and vegetables of worth1000 UZS requires only 10 m^3 (8.9 m^3 USD^{-1}) of water, while it is 11 m^3 (10.2 m^3 USD^{-1}) for similar valued fodder crops. The prices for these commodities are high, most likely because no government production quotas and procurement prices exist for these crops. Among the industrial sectors, the highest direct water consumption per 1000 UZS equivalent is estimated for the energy industry with a value of 3.0 m^3 (2.7 m^3 USD^{-1}). Although the non-agricultural sectors produced about 75% of GDP in 2005, they consume less than 10% of all total water resources. Hence their direct water use per unit of production is negligible.

The virtual water multipliers (VWMs), or total water input coefficients to produce a unit of the final demand, are again higher in crop production (except ‘other crops’) than in other sectors. VWM of livestock husbandry is substantially lower than VWMs of the other agricultural sectors. VWMs for most of the sectors are considerably higher than the direct water input coefficient for these sectors. The most noticeable differences between these two indicators are observed for livestock, chemical industry, cotton processing, light industry, and food processing. The large difference between VWMs and direct water uses for cotton processing, light industry, and food processing are due to a high water demand for producing intermediate inputs consumed by these sectors. However, virtual water content of these sectors is still lower than that of agricultural sectors. For instance, when cotton and food processing demands about 15 and 5.7 m^3 10^{-3} UZS^{-1} (13.3 and 5.1 m^3 USD^{-1}) virtual water use respectively, raw cotton production and fruits and vegetables cropping requires 20 and 11 m^3 10^{-3} UZS^{-1} (18.4 and 9.5 m^3 USD^{-1}) correspondingly.

Concurrently, forward linkage based virtual water contents are higher and substantially larger than the direct water use for the sectors such as energy industry, oil and gas mining, chemical industry, and trade. However, in general, virtual water content in terms of forward linkage for crop production sectors except the other crops is higher than that of the remaining sectors while it insignificantly differs from the virtual water content level in terms of backward linkage index.

Integrated economic potential and environmental acceptability of all sectors are further analyzed by grouping them into four clusters according to three impact indicators - adjusted BLIs, FLIs, and VWMs (Figure 7 and Figure 8). Clear borders between Cluster 1 and Cluster 3 are hardly shown in terms of their BLIs and VWMs. However, the case that FLIs for Cluster 1 are substantially higher than FLIs for Cluster 3 clearly determines the borders between them. These clusters include mainly high water use intensive agricultural and agro-processing industries with widely variable BLIs. Cluster 2 comprises the highly water-efficient Oil and gas industry, Machinery, Trade, and Transport and communications sectors with low levels of BLI and high levels of FLI. In contrast, Cluster 4 is characterized by a medium level of FLI, BLI, and VWM. Since no any cluster is distinguishingly better than the remaining clusters according to the all tested criteria, it is hard to decide to select one as the best. Nevertheless, Cluster 4 can be defined slightly more efficient in economic performance and water use terms than the remaining clusters since no lowest FLI, BLI, and VWM values are observed in this cluster. The least favorable group is Cluster 3 with the lowest values of BLI, FLI, and VWM. However, since clustering provides generalized picture over the preference to the group of different sectors, comparison of the sectors within the clusters are still relevant to obtain detailed picture on the rank of the sectors according to multiple criteria.



Clusters	Sectors (Case number)	BLI	FLI	VWM
Cluster 1	Cotton (1), Fodder (5), Energy industry (8), Chemical industry (11)	0.82-1.22	1.09-1.59	0.66-20.8
Cluster 2	Oil and gas (9), Machinery (12), Trade (18), Transport and communications (19)	0.79-0.95	0.91-1.52	0.17-0.23
Cluster 3	Winter wheat (2), Rice (3), Gardening (4), Other crops (6), Livestock (7), Cotton processing (13), Light industry (14), Food industry (15)	0.75-1.45	0.60-0.88	1.05-39.9
Cluster 4	Metallurgy (10), Other industries (16), Construction (17), Other services (20)	0.94-1.22	0.81-1.11	0.25-0.48

Fig. 7 Classification of sectors according to adjusted Backward Linkage Index (Adj_BLI), Forward Linkage Index (Adj_FLI), and Virtual Water Multiplier (Adj_VWM)

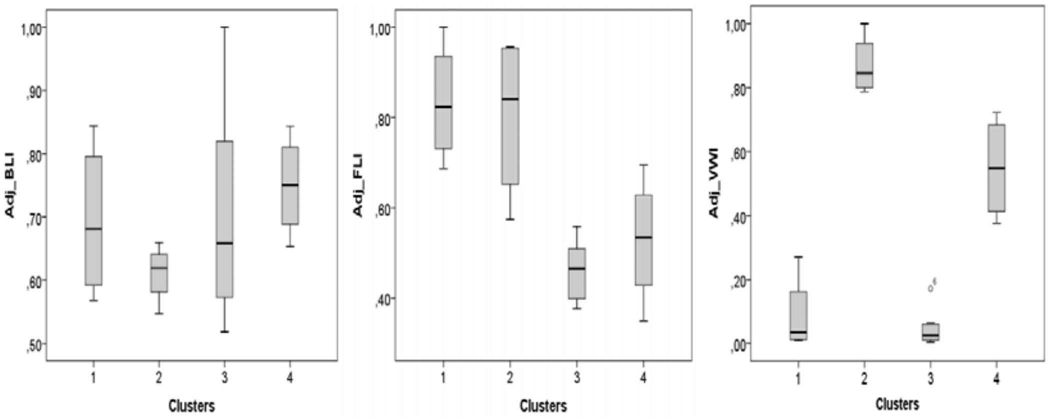


Fig. 8 Mean and variation of adjusted Backward Linkage Indices (Adj_BLIs), Forward Linkage Indices (Adj_FLIs), and Virtual Water Multipliers (Adj_VWMs) by the clusters of economy sectors

Discussion

Reaching a “green–growth” based economic development is dominating the worldwide debate on achieving sustainable growth. This debate presently centers on (i) which production technologies can be adjusted and (ii) how to decouple economic growth from the consumption of critical natural resources such as land and water. This is particularly challenging in countries of dryland regions, such as Uzbekistan, which has a strong dependence of irrigated agriculture for supporting economic development in general and for a sustainable growth (green economy) in particular. The combined effects of the predicted impact of climate change in Central Asia (Chub, 2000, 2007), the increased focus of upstream countries in the region for hydropower generation (Eshchanov *et al.*, 2011), and population growth will decrease the availability of irrigation water for the country beyond doubt. This poses challenges to downstream countries like Uzbekistan to identify restructuring policies guided by less water-intensive industrial and services sectors, crop diversification, and a modernized agricultural sector adopting of water-saving technologies (Bekchanov *et al.*, 2010). This, in turn, would require a prioritization of sectors for efficient investment allocations, and considering in particular the availability of present and future water resources in addition to economic linkage indicators. While using an input-output model, we identify potential key sectors for economic restructuring based on the comparison of economic impact and environmental sustainability indexes concurrently.

The findings for the case study Uzbekistan, as an example of a dryland country, together with other studies of Velazquez (2006) and Dietzenbacher and Velázquez (2007) for Spain, or Lenzen and Foran (2001) and Lenzen (2003) for Australia, and from Feng *et al.* (2011) for the United Kingdom and Zhao et al. (2009) for China, illustrate that the input-output model approach is a powerful tool to estimate and compare virtual water requirements of different sectors in the economy. Yet, to exploit the potential of this instrument, reliable and accurate information on the different sectors of the economy are required to achieve better accuracy when estimating intersectoral financial flows. Saying this, data mismatches which usually occur when being dependent on different data sources imply making calculated assumptions, as was needed in this analysis with regards to the export values, or accept a certain inaccuracy of the findings. Yet, the availability of different data sources has the advantage of permitting cross-checking results which increases the confidence of the estimated values as was shown during the analyses here.

The findings indicate that crops with large amounts of virtual water consumption per economic output, such as cotton, wheat, and rice, still dominate the agricultural sector in Uzbekistan. Because of welfare and employment concerns, cotton production continues on at least 40% of the total irrigated cropland as the farmers follow strict government cotton land and production quota (Djanibekov, 2008). As a consequence, development of industry, human capital, and market infrastructure are still focused on cotton production and export. Obviously, even though cotton production is acknowledged for increasing welfare to many rural inhabitants and securing livelihood in the past four decades in Central Asia (Rudenko *et al.*, 2012), it is also well-known fact that the past cotton production practices have contributed to the environmental disaster which is known as the Aral Sea syndrome (WBGU, 1998). Relying on risky water resources accompanied by environmental degradation as well as uncertain prices for primary commodities in the world market for maintaining export income and living standards, Uzbekistan would in the long run be confronted with an environmental-economic dilemma through increasing dependency on an unsustainable economy and further degradation of environmental quality. In order to maintain long-term sustainability and growth of real income, the country should restructure its domestic economy by directing precious resources towards low water intensive and high value-adding sectors.

Although it is generally argued that the production of 1 kg of livestock products, such as meat, milk and eggs, requires much higher virtual water than the production of agricultural commodities such as cereals (e.g. Chapagain and Hoekstra, 2003; Chapagain and Hoekstra, 2004; Mekonnen and Hoekstra, 2010), virtual water required per economic output of the livestock sector in Uzbekistan turns out to be lower than that of the crop production sectors. Maintenance and further development of livestock husbandry seems, therefore, to be more promising pathway given the higher economic growth linkage and due to lower water requirements per economic output compared to other agrarian subsectors. To exploit this potential option demands, however, an adequate fodder production that is not considered by farmers and policy makers at present. Although this line argumentations are based on average value of virtual water content due to limitedness of the Leontief model to show marginal water productivities which is a key in economic decisions, this argumentations are in line with those of previous partial and general equilibrium model based regional agricultural analyses which postulates higher profitability and environmental sustainability when developing in particular the livestock sector (Bekchanov et al, 2012; Djanibekov, 2008; Müller, 2006). Moreover, nitrogen-fixing forage crops can play a crucial role in saving fertilizer and improving soil fertility when added to crop rotations (Djumaniyazova *et al.*, 2010).

The same reasoning can be applied to the development of the fruit and vegetables production sector. The development of vegetables and fruits production, however, must go hand in hand with the creation of storage capacities and processing facilities that have deteriorated following independence (Bobojonov and Lamers, 2008). The pursuit of such combined strategies can contribute to stabilize fruits and vegetables prices. The present practice of differential crop support in Uzbekistan creates disincentives for farmers to use water resources more efficiently, implement crop diversification and maintain crop rotations (Djanibekov, 2008; Bobojonov *et al.*, 2012). In order to maintain sustainable resource use, the cotton monoculture support should either be phased out, or equal importance should be given to the remaining crops.

Our analyses also show that a further development path could include the promotion of agro-processing industries rather than solely concentrating on the production of agricultural raw commodities. This pathway would also contribute to reach the aim of more sustainable economic growth, while depending less on uncertain water resources. This finding is in line with conclusions of the study by Rudenko *et al.* (2009) which underline that supporting the development of the cotton value chain and increasing the production of value added commodities in this chain such as clothes bear the option of higher income generation for producers. Alternatively, when pursuing change in the current cotton value chain, substantial cropland area under cotton can be released without any decrease in total income and these lands become potentially available for other, more water productive crops (Rudenko *et al.*, 2009). However, the lack of financial assets, technologies, and specialists impedes presently the further development of the highly and more stably profitable agro-processing sectors. On the other hand, although water requirements in the industrial sector are much lower than in the agricultural sector, waste water from industrial processes is known to be much more hazardous than the return water flows in agriculture (Chapagain and Hoekstra, 2004). Thus, the development of the agro-processing should take into account these options to decrease the negative influence of the return flows on natural ecosystems as well.

Indeed, in terms of economic impact and virtual water content, the development potential of non-agro-processing industries and services sectors is higher than that of any agricultural or agro-processing industries. Particularly the energy industry, chemical industry, and construction materials production sectors are identified as the key sectors of the economy according to their BLI and FLI, while having very low water requirements. However, return flows and hazardous atmospheric emissions from the industrial sectors are much more harmful to environment than those of agriculture-based sectors. Since our analyses exclude environmental factors other than virtual water use, inclusion of more environmental factors would improve the results discussed and would enable to make more reliable conclusions on the sustainable development potential of the industrial sectors in Uzbekistan.

Cluster analysis of the sectors performed show that clustering can be employed as an alternative to ordering since the latter is complex when multiple criteria are considered. However, clusters also are not easy to prioritize or rank since none of them is distinguishingly better than the remaining when equal weights are given to all criteria (BLI, FLI, VWM). Considering different weights to the different criteria by the analysts may ease ordering the clusters and selecting the best. For instance, if higher weight is considered for water productivity, Cluster 2 and Cluster 4 can be preferred over the others. Similarly, when FLI is more important Cluster 1 and Cluster 2 are more preferable and when BLI is prioritized Cluster 4 is more advantageous.

The results discussed here are useful only comparing the sectors to each other according to economic and efficient water use criteria defined by BLI, FLI, and VWM. Prioritizing any sector to the other should depend on the weight to the criteria given by decision makers and thus the results obtained here should be carefully considered while not forgetting weighting and other factors. We acknowledge that the indicators discussed here are not only options to select the key sectors for sustainable growth. International comparative advantages, technology access, human capital, innovation and knowledge interactions, social networks, institutional settings, income distribution, and many other economic and ecologic indicators play important role to determine key sectors for economic growth (Bryan *et al*, 2005). Nevertheless, our analysis can be complementary to more comprehensive multicriteria multisectoral quantitative and qualitative analysis of determining key sectors for economic growth mentioned by Bryan et *al*. (2005).

Summary and Conclusions

Sustainable economic development necessitates an integration of economic and ecological impact indicators to lay the basis for better-informed policy decisions. The necessary consideration of environmental impact in development strategies is vital, particularly, for countries located in dry and semi-dry zones of the world. This study develops an input-output model for assessing and comparing the development potential of sectors in the economy with respect to efficient water use and economic development impact. We illustrate the example of Uzbekistan, a country located in the center of the Eurasian continent and characterized by water shortages due to its arid to semi-arid climate, increased upstream-energy and downstream-irrigation water use disputes, deteriorated water infrastructure, mounting investment costs, and low financial maintenance. In order to avoid the risks of environmental degradation and consequent economic crisis in the long run, Uzbekistan needs to restructure its domestic production with more emphasis on higher value-adding and less water-intensive sectors and commodities. Since the agricultural sector requires already more than 90% of overall water used in the economy, it is imperative to implement policies that induce the adoption of water conservation technologies as well as crop pattern change towards more water productive crops. Transforming the economy towards the industrial sectors, and upgrading agricultural value chains would result in a more efficient use of the expected limited water resources. Moreover, these reforms could prevent potential conflicts among the water users in the region and sectors in the Aral Sea Basin. Particularly, policies inducing more crop diversification by increasing the area under crops such as fruits, vegetables, and fodder crops could benefit not only farmers, but also consumers due to the consequence of lower prices for such commodities. Such crop diversification also can help to enhance soil fertility by crop rotations. Concurrently, the accompanying development of agro-processing industries while reducing the area of high water intensive crops would facilitate to increase the value addition with the use of less amounts of water. However, a successful implementation of economic diversification policy would be possible and sustainable only if necessary market infrastructure, human resources potential and proper treatment of industrial return flows were to be provided. Although according to the strength of economic linkages, the energy industry, chemical industry, and construction materials production are found to be the key sectors in the Uzbek economy with high water productivity, more detailed research focusing on other environmental impact indicators, such as carbon emissions and waste water discharges would allow more reliable conclusions about the potential for sustainable development in Uzbekistan. Moreover, since international comparative advantages, technological upgrading, institutional and governance settings, and many other factors as well as the weights for these criteria which are subject to the decision makers are also essential in key sector assessment, our analysis can be only part of the integrated multicriteria framework which considers all the above mentioned quantitative and qualitative parameters for determining key sectors for sustainable economic growth.

References

Asian Development Bank (ADB) (2008) Key economic indicators (Online database). http://www.adb.org. Accessed 20 August 2008

Australian National Water Commission (ANWC) (2008) Distilled (eNewsletter). http://www.nwc.gov.au/__data/assets/pdf_file/0005/11885/DistilledJuly2008.pdf. Accessed 21 May 2011

Bekchanov M, Lamers JPA, Martius C (2010) Pros and Cons of Adopting Water-Wise Approaches in the Lower Reaches of the Amu Darya: A Socio-Economic View. Water, 2: 200-216. doi:10.3390/w2020200

Bekchanov M, Müller M, Lamers JPA (2012) A computable general equilibrium analysis of agricultural development reforms: national and regional perspective. In: Martius C, Rudenko I, Lamers JPA, Vlek PLG (eds) Cotton, water, salts and soums - economic and ecological restructuring in Khorezm, Uzbekistan. Springer: Dordrecht/Heidelberg/London/New York, pp 347-370

Beyers WB (1976) Empirical identification of key sectors: some further evidence. Environ Planning A 8: 231-236. doi:10.1068/a080231

Bharadwaj KR (1966) A note on structural interdependence and the concept of a key sector. Kyklos 19: 315-319

Bobojonov I, Lamers JPA, Djanibekov N, Ibragimov N, Begdullaeva T, Ergashev A, Kienzler K, Eshchanov R, Rakhimov A, Ruzimov J, Martius C (2012) Crop diversification in support of sustainable agriculture in Khorezm. In: Martius C, Rudenko I, Lamers JPA, Vlek PLG (eds) Cotton, water, salts and soums - economic and ecological restructuring in Khorezm, Uzbekistan. Springer, Dordrecht/Heidelberg/London/New York, pp 219-233

Bobojonov I, Lamers JPA (2008) Analysis of agricultural markets in Khorezm, Uzbekistan. In: Wehrheim P, Shoeller-Schletter A, Martius C (eds) Continuity and Change: land and water use reforms in rural Uzbekistan. Socio-ecnomic and legal analyses for the region Khorezm. IAMO, Halle/Saale, pp 165-182

Bobojonov I (2008) Modelling Crop and Water Allocation under Uncertainty in Irrigated Agriculture: A Case Study on the Khorezm Region, Uzbekistan. Dissertation, ZEF/Bonn University

Bryan J, Jones C,MundayM (2005) Investigating the potential of key sectors using multisectoral qualitative analysis: a Welsh case study. Environ Plann C 23(5): 633–656

Center for Efficient Economic Policy (CEEP) (2006) Economy of Uzbekistan (Statistcial analytical review). CEEP, Tashkent, Uzbekistan

Cella G (1984) The Input-Output Measurement of Interindustry Linkages. Bull Oxford Univ Inst Econ Statist 46(1): 73-84

Chapagain AK, Hoekstra AY, (2007) The water footprint of coffee and tea consumption in the Netherlands. Ecolog Econ 64(1): 109-118

Chapagain AK, Hoekstra AY (2004) Water footprints of nations. Value of Water Research Report Series No.16, Vol. 1, UNESCO-IHE, Delft, Netherlands

Chapagain AK, Hoekstra AY (2003) Virtual water flows between nations in relation to trade in livestock and livestock products. Value of Water Research Report Series No.13, UNESCO-IHE, Delft, Netherlands

Chenery HB, Watanabe T (1958) Internatioinal comparisons of the structure of production. Econometrica 26: 487–521

Chub VE (2000) Climate change and its impact on natural resources potential of the Republic of Uzbekistan. Main Administration on Hydrometeorology under the Cabinet of Ministers of the Republic of Uzbekistan/Central Asian Hydrometeorological Research Institute named after V.A. Bugayev, Tashkent, Uzbekistan

Chub VE (2007) Climate change and its impact on hydrometeorological processes, agro-climatic and water resources of the republic of Uzbekistan. Center for Hydro-meteorological Service under the Cabinet of Ministers of the Republic of Uzbekistan (Uzhydromet) / Scientific and Research Hydro-meteorological Institute (NIGMI), Tashkent, Uzbekistan

Clark C (1940, revised and reprinted in 1951) The Conditions of Economic Progress. MacMillan & Co. Ltd., London

de Mesnard L (2009) Is the Ghosh model interesting? J Reg Sci 49 (2): 361-372

CRIIWRM (Central Research Institute of Integrated Water Resources Management – Sentralniy Nauchno-Issledovatelskiy Institut Kompleksnogo Ispolzovaniya Vodnih Resursov) (1980) Aggregated norms of water use and discharge in animal husbandry and in rural settlements with centralized water sewage system. CRIIWRM, Minsk

Dietzenbacher E (1997) In vindication of the Ghosh model: a reinterpretation as a price model. J Reg Sci 37: 629–651

Dietzenbacher E, Velázquez E (2007) Analysing Andalusian Virtual Water Trade in an Input-Output Framework. Reg Stud 41(2): 185-196

Djanibekov N (2008) A Micro-Economic Analysis of Farm Restructuring in Khorezm Region (Uzbekistan). Dissertation, Bonn University

Djumaniyazova Y, Sommer R, Ibragimov N, Ruzimov J, Lamers JPA, Vlek P (2010) Simulating water use and N response of winter wheat in the irrigated floodplains of arid Northwest Uzbekistan, Central Asia. Field Crop Res 116(3): 239-251

Duarte R, Yang H (eds) (2011) Special Issue: Input-Output and Water: Introduction to Special Issue. Econ Systems Res 23(4): 341-351

Ekins P (2000) Economic growth and environmental sustainability: the prospects for green growth. Routledge, Landon/New York

Eshchanov BR, Stultjes MGP, Salaev SK, Eshchanov RA 2011. Rogun Dam—Path to Energy Independence or Security Threat? Sustainability 3(9): 1573-1592

FAO 2000. Carbon sequestration options under the Clean Development Mechanism to address land degradation. World Soil Resources Reports No. 92, Food and Agriculture Organization of the United Nations, Rome

Feng K, Chapagain A, Suh S, Pfister S, Hubacek K (2011a) Comparison of Bottom-Up and Top-Down Approaches to Calculating the Water Footprints of Nations. Econ Systems Res 23 (4): 371-385. DOI: 10.1080/09535314.2011.638276

Feng K, Hubacek K, Minx J, Siu YL, Chapagain A, Yu Y, Guan D, Barrett J (2011b) Spatially Explicit Analysis of Water Footprints in the UK. Water, 3(1): 47-63

Foran B, Lenzen M, Dey C, Bilek M (2005) Integrating Sustainable Chain Management with Triple Bottom Line Reporting. Ecol Econ 52: 143-157

Fourastié J (1949). Le Grand Espoir du XXe Siècle. Paris: Presses Universitaires de France. Reprinted as 'Moderne Techniek en Economische Ontwikkeling' (1965). Het Spectrum, Amsterdam

Gallego B, Lenzen M (2005) A consistent input-output formulation of shared producer and consumer responsibility. Econ Systems Res 17(4): 365-391

Golan A, Judge G, Miller D (1996) Maximum entropy econometrics: robust estimation with limiteddata. John Wiley & Sons, Chichester, UK

Ghosh A (1958) Input-Output Approach in an Allocation System. Economica 25: 58-64

Glantz MH (ed) (1999) Creeping Environmental Problemsand Sustainable Development in the Aral Sea Basin. Cambridge University Press, Cambridge, UK

Hazari BR (1970) Empirical Identification of Key Sectors in the Indian Economy. Rev Econ Statist 52 (3): 301-305

Hewings GJD (1982) The Empirical Identification of Key Sectors in an Economy: A Regional Perspective, The Developing Economies 20: 173-195

Hirschman AO (1958) The Strategy of Economic Development. Yale University Press, New Haven, CT, USA

Jones LP (1976) The Measurement of Hirschman Linkages. Quart J Econ 90(2): 323-333

Lenzen M (2009) Understanding virtual water flows: A multiregion input-output case study of Victoria. Water Resources Res 45, W09416, doi:10.1029/2008wr007649

Lenzen M (2003) Environmentally important paths, linkages and key sectors in the Australian economy. Struct Change Econ Dynam 14(1): 1–34

Lenzen M Foran B (2001) An input–output analysis of Australian water usage. Water Policy 3: 321-340

Leontief W (1951) The structure of the American economy. Second edition. University Press, New York / Oxford

Leontief W (1936) Quantitative Input-output relations in Economic System of the United States. Input-output economics. Rev Econ Statist 18: 105-125

MacQueen JB (1967) Some methods for classification and analysis of multivariate observations. Proceedings of 5th Berkeley Symposium on Mathematical Statistics and Probability. University of California Press, Berkeley, 281–297. http://projecteuclid.org/euclid.bsmsp/1200512992. Accessed 5 January 2012

Mardia KV, Kent JT, Bibby JM (1979) Multivariate Analysis. Academic Press, London.

McKinley T (2008) Uzbekistan: From Import Substitution to Export Boom. In: Development Digest: The Resource Curse. Centre for Development Policy and Research, pp 12-13

Mekonnen MM, Hoekstra AY (2010) The green, blue and grey water footprint of farm animals and animal products. Value of water research report series No. 48, UNESCO-IHE, Delft, Netherlands

Midmore P, Munday M, Roberts A (2006) Assessing Industry Linkages Using Regional Input-Output Tables. Reg Stud 40(3): 329-343

Millenium Ecosystem Assessment (2005) Ecosystems and Human Well-being: Desertification synthesis. World Resources Institute, Washington DC, US

Miller RE, Lahr ML (2001) A taxonomy of extractions. In: Lahr ML and Miller RE (eds), Regional Science Perspectives in Economics: A Festschrift in Memory of Benjamin H. Stevens. Amsterdam: Elsevier Science, pp 407–441

Müller M (2006) A General Equilibrium Modeling Approach to Water and Land Use in Uzbekistan. Dissertation, Bonn University

National Statistical Committee (UzStat) (2008) Statistical Yearbook, 1991-2007. Statistical buelletin. UzStat, Tashkent, Uzbekistan

National Statistical Committee (UzStat) (2006) Industry in Uzbekistan. Statistical buelletin. UzStat, Tashkent, Uzbekistan

Orlovsky N, Glanz M, Orlovsky L (2000) Irrigation and Land degradation in the Aral Sea Basin. In: Breckle SW, Vesle M, Wuecherer W (eds) Sustainable Land Use in Deserts. Springer Verlag, Heidelberg, Germany, pp 115-125

Oosterhaven J (1988) On the plausibility of the supply-driven input-output model. J Reg Sci 28: 203–217

Oosterhaven J (1989) The supply-driven input-output model: a new interpretation but still implausible. J Reg Sci 29: 459–465

Oosterhaven J (1996) Leontief versus Ghoshian price and quantity models. Southern Econ J 62: 750–759

Oosterhaven J, Stelder D (2002) Net multipliers avoid exaggerating impacts: with a bi-regional illustration for the Dutch transportation sector. J Reg Sci 42: 533–543

Rasmussen PN (1956) Studies in Intersectorial Relations. North-Holland, Amsterdam

Roll G, Alexeeva N, Aladin N, Plotnikov I, Sokolov V, Sarsembekov T, Micklin P (2006) Aral Sea experience and lessons learned brief. In: Managing Lakes and their Basins for Sustainable Use: A Report for Lake Basin Managers and Stakeholders. Lake Basin Management Initiative, Kusatsu, Japan. http://www.ilec.or.jp/eg/lbmi/. Accessed 28 June 2011

Rosegrant M, Cai X, Cline SA (2002) World Water and Food to 2025 – Dealing with Scarcity. IFPRI, Washington DC, US

Rudenko I, Nurmetov K, Lamers JPA (2012) State order and policy strategies in the cotton and wheat value chains. In: Martius C, Rudenko I, Lamers JPA, Vlek PLG (eds) Cotton, water, salts and Soums: economic and ecological restructuring in Khorezm, Uzbekistan. Springer, Dordrech/Berlin/Heidelberg/New York, pp 371-388

Rudenko I, Lamers JPA, Grote U (2009) Could Uzbek farmers get more for their cotton? Europ J Devel Res 21(2): 283-296

Smajgl A, Liagre L (2010) Analysing implications of limited water availability for Great Barrier Reef catchments. Econ Systems Res 22(3): 263-277

Sonis M, Guilhoto JJM, Hewings GJD, Martins EB (1995) Linkages, key sectors, and structural change: some new perspectives. Developing Economies 33: 233-270

State Construction Bureau (SEV and VNI VODGEO Gosstroya SSSR) (1978) Aggregated norms of water consumption and sewage in various sectors of industry. Stroyizdat, Moscow

Strassert G (1968) Zur bestimmung strategischer sektoren mit hilfe von von input-output modellen. Jahrbucher fur National okonomie und Statistik 182: 211–215

Sutton W, Whitford P, Stephens EM, Galinato SP, Nevel B, Plonka B, Karamete E (2008) Integrating Environment into Agriculture and Forestry: Progress and Prospects in Eastern Europe and Central Asia. The World Bank, Washington DC, US

United Nations Economic and Social Comission for Asia and the Pacific (UN ESCAP) (2009) Eco-efficiency Indicators: Measuring Resource-use Efficiency and the Impact of Economic Activities on the Environment. Bangkok, Thailand. http://www.greengrowth.org. Accessed 05 January 2012

United Nations Development Program (UNDP) (2007) Water - critical resource for Uzbekistan's future. UNDP Energy and Environment Unit, Tashkent, Uzbekistan

United Nations Development Program (UNDP) (2006) Modeling the impact of changes in tax rates on key macroeconomic parameters. UNDP, Tashkent, Uzbekistan

UNSD (2011) System of Environmental-Economic Accounting for Water. United Nations Statistics Division, New York, US. http://unstats.un.org/unsd/envaccounting/water.asp. Accessed 5 January 2012

Van Oel PR, Mekonnen MM, Hoekstra AY (2009) The external water footprint of the Netherlands: Geographically-explicit quantification and impact assessment. Ecolog Econ 69(1): 82-92

Vardon M, Lenzen M, Peevor S, Creaser M (2006) Water accounting in Australia. Ecolog Econ 61: 650-659

Velazquez E (2006) An input–output model of water consumption: Analysing intersectoral water relationships in Andalusia. Ecolog Econ 56: 226–240

WBGU (German Advisory Council on Global Change) (1998) Worlds in transition: Ways towards sustainable management of fresh water resources. Springer-Verlag, Berlin

Zhao X, Chen B, Yang ZF (2009) National water footprint in an input-output framework - A case study of China 2002. Ecol Model 220(2): 245-253