# ASSESSMENT OF PHYSICAL ECONOMY THROUGH MATERIAL FLOW ANALYSIS FOR ESTABLISHING SUSTAINABLE SOCIETY IN UZBEKISTAN

（ウズベキスタンにおける持続社会形成のための物質フロー解析による物質経済の分析）

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Doctor of Engineering



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# Declaration

*I, the undersigned, declare that this thesis submitted to the Toyohashi University of Technology for the degree of Doctor of Philosophy in the department of Environmental and Life Sciences and the work contained herein is my original work with exemption to the citations and that this work has not been submitted at any other university, either in part or in its entirely, for the award of any degree.*

*Ozoda Yuldasheva, November 27, 2015*

# Abstract

Over the past decades, an increased demand on natural resources is considered a serious threat to well-functioning economies and societies due to the environmental problems associated with them, such as, desertification, ecosystem degradation, and climate change. The main driver behind human-induced environmental changes has been growing social or industrial metabolism, that is, "the inputs of materials and energy into socio-economic systems and the corresponding outflows of wastes and emissions" (*Fischer-Kowalski et al., 1998; Matthews et al., 2000; Haberl et al., 2004*). The United Nations defines sustainability as a global process of development that minimizes the use of environmental resources and reduces the impact on environmental sinks using processes that simultaneously improve the economy and the quality of life (*UN World Commission on Environmental and Development, 1987*). A better understanding of the patterns and trends of changes in a nation's social metabolism helps us understand the dynamics of human-environment relations.

This study pioneers in assessing the physical dimensions of Uzbekistan's economy in the period of 1991-2012. This is the first study that takes Uzbekistan as its primary focus. The transition from state-planned governance to a market economy, after the country gained its independence in 1991, brought numerous reformations into the socioeconomic system. The metabolic profile of the country has been significantly altered due to the economic growth and population increase in the afore-mentioned transition period.

The research portrays the macroscopic picture of physical economy of Uzbekistan using a Material Flow Analysis (MFA) method, an internationally recognized tool for such assessments. MFA covers all material inputs, apart from water and air, available to a national economy in the metric system of tonnes on a yearly basis. The material flows data set is comprised of consistent data for domestic extraction (DE), the number for imports and exports as well as information on derived material flow indicators. The main material sub-categories analyzed in this study are fossil fuels, biomass and minerals. There have been a number of studies using methodological standardization of MFA, but to the best of my knowledge, the method has never been used to assess the metabolism of Central-Asian economies, particularly the case of the Republic of Uzbekistan.

Our analysis on evaluation of macroscopic economic activities in Uzbekistan showed that the input indicators of direct material input (DMI) and total material requirements (TMR) have slightly increased with an average growth rate (AGR) of 2.8% and 2.3% during period of study. The trends of GDP per DMI indicated that the material efficiency of the economy has continued to increase from 57.4 in 1992 to 87.7 USD per tonne in 2011, with an AGR of 2.6%.

Since the second decade of study relative decoupling has occurred. In three-phased period over two decades, we observed the close relationship between the economy-wide MFA based indicators and the government's macro policy implementation.

Next we assessed the main drivers of material use in the socio-metabolic transition through disaggregated MFA in Uzbekistan by a range of categories and sub-categories. In per capita terms, the DE has increased from 9.8 to 10.9 tonnes in 1991-2012. Biomass extraction increased with the highest AGR of 3.6%. In terms of physical trade balance (PTB) Uzbekistan transferred to be a net exporter of fossil fuels and net importer of biomass products in the second decade of the study period. DMC has increased with an AGR of 1.8% mainly driven by biomass 3.6% and construction minerals 2.8% used in the period of study. The environmental impact analysis through the IPAT model depicted that the development of DMC in Uzbekistan is mostly driven by economic growth and technological change during its transition period.

Through the initial assessment of energy transition by developed set of MFA-based energy indicators for Uzbekistan, we obtained the information that confirms significant reduction in energy imports dependency, and the domestic energy extraction (DEE) was dominant (96%) in total energy input in the country since the second decade of transition. On average natural gas was dominant in domestic energy consumption (DEC) and energy exports with the share of 81% and 72%, respectively. Although energy intensity DEC per GDP is contracted from 1.7 to 0.5 kg per USD, Uzbekistan is still highly dependent on fossil fuels despite the high potential on renewable energy sources available in the country. However, in the environmental assessment we obtained data that confirms the fact of total energy requirement (TER) decrease with an AGR of -0.5%, and the hidden energy flows presented a lower level of environmental impacts in Uzbekistan due to the reduction of energy imports and the dominance of natural gas as an energy source. Natural gas has a lower ratio in calculation of hidden energy flows.

The research summarizes that the development within all categories of material flows was indispensable for the socio-economic development of Uzbekistan in the transition period. The management of all material flows plays a major role in two important tasks: firstly, achieving society's main objectives by extensive access to grain and energy products, and secondly the development of economic performance of the country by increasing industrial base and export commodities. However, the economic development and increase of industrial base caused the growth in resource consumption accompanied with waste and pollution to the environment in Uzbekistan. Based on our observations and findings, we suggest to employ integrated system for sustainable production and consumption in this Central-Asian country. We also believe that the emphasis should be given to sustainable and effective management of resources in the medium and long term prospective.

# Abbreviations

| | |
|---|---|
| MFA | Material Flow Analysis |
| EW-MFA | Economy-wide Material Flow Analysis |
| DE | Domestic Extraction |
| UDE | Unused Domestic Extraction |
| IMP | Imports |
| IFI | Indirect Flows associated to Imports |
| EXP | Exports |
| IFE | Indirect Flows associated to Exports |
| PTB | Physical Trade Balance |
| DMI | Domestic Material Input |
| DMC | Domestic Material Consumption |
| TMR | Total Material Requirement |
| DPO | Domestic Processed Output |
| HF | Hidden Flows |
| DEE | Domestic Energy Extraction |
| DEI | Domestic Energy Input |
| DEC | Domestic Energy Consumption |
| $IMP_e$ | Energy imports |
| $EXP_e$ | Energy exports |
| TER | Total Energy Requirement |
| TEC | Total Energy Consumption |
| GDP | Gross Domestic Products |
| POP | Population |
| SCS | The State Committee of the Republic of Uzbekistan on Statistics |
| WB | The World Bank |
| EU | European Union |
| CAC | Central Asia Countries |
| UK | United Kingdom |
| Mt | Million tonnes |
| Mtoe | Million ton oil equivalent |
| AGR | Average Growth Rate |
| USD | United States of Dollar |

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**Assessment of physical economy through economy-wide material flow analysis in developing Uzbekistan**



## CHAPTER IV

**Drivers of material use during the transition from state-planned to market based economy: the case of Uzbekistan 1991-2012**

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## CHAPTER VI



**APPENDICES**

# List of Publications

1. Ozoda RAUPOVA, Hirotsugu KAMAHARA and Naohiro GOTO, "*Assessment of physical economy through economy-wide material flow analysis EW-MFA in developing Uzbekistan*", International Journal Resources, Conservation and Recycling, Vol 89, pp.76-85, 2014.

2. Ozoda YULDASHEVA, Lindsay PRESCOTT and Naohiro GOTO, "*Assessment of energy transition through "MFA-based energy indicators set" in a transition economy - Uzbekistan*", Journal of Japan Association for Human and Environmental Symbiosis. In press, 2015.

3. Ozoda RAUPOVA and Naohiro GOTO, "*Energy transition and renewable energy through material flow analysis perspectives in developing Uzbekistan*", O-Po-2-4, p4, International conference, 2014.7.27~ 2014.8.1., Tokyo Big Sight, Tokyo Japan.

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# CHAPTER I

# INTRODUCTION

# 1.1 Background

Resources are indispensable for human life. To produce goods or provide services, resources are constantly gathered from the environment. Today, we use approximately 50% more of those resources than we did 30 years ago. In the early 21 century, humanity used approximately 68 billion tons of materials each year, 10 times as much as a 100 years earlier, and this trend has continued to grow at rate of 3.4% per year (*Krausmann et al., 2009*). The main driver behind human-induced environmental change has been the growing social or industrial metabolism, that is, "the inputs of materials and energy into socio-economic systems and the corresponding outflows of wastes and emissions" (*Fischer-Kowalski et al., 1998; Matthews et al., 2000; Haberl et al., 2004*). Given current trends of growth, our extraction of natural resources could increase to 100 billion tonnes by 2030 (*SERI, 2009*).

However, humanity's rapidly growing consumption of these resources has caused many environmental changes. The environment cannot infinitely sustain the increasing drain of energy and material resources that has occurred over the last few decades. The Intergovernmental Panel on Climate Change group of scientific experts concluded there's a more than 90 percent probability that human activities over the past 250 years have warmed our planet. Since the industrial revolution began humans have increased atmospheric carbon dioxide concentration by a third (*IPCC, 2014*).

Continuous increase of resource use brings a serious threats not only to the environment but also can raise some social issues such as unfair distribution of resources (inequality), human rights violation and poverty (*MDG, 2010; Griggs et al., 2013*). Uprising a big gap in environmental and social standards between least developing countries such as those in Africa and most developed countries such as European or North American countries can be seen over past decades. According to *Schaffartzik et al., (2014)* investigation, for the year 2010, consumption of natural resources per capita in the western industrial countries is 41 kg per day while in Sub-Saharan Africa people consume only 12kg per day.

Sustainability has been defined by the United Nations as a global process of development that minimizes the use of environmental resources and reduces the impact on environmental sinks using processes that simultaneously improve the economy and the quality of life. Sustainable development has many definitions, however, the most frequently quoted definition is, "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs," (*UN World Commission on Environmental and Development, 1987*).

Problem regarding sustainability lies within the society-nature interaction. It needs to observe societies, natural systems, and their interaction over time. The physical basis of our society always has the linkages of processes and product chain webs within the anthroposphere and the exchange of materials and energy within the environment. Action on sustainable consumption and production at the regional and national level focuses on the sustainable and efficient management of resources at all stages of value chains of goods and services, and encourages the development of processes that use fewer resources and generate less waste, including hazardous substances, while yielding environmental benefits and frequently productivity and economic gains (*UNEP, 2015*). Studies of social and industrial metabolism aim to provide an understanding of the functioning of biophysical structure of society.

Societal change during a country's industrialization phase can be described as a socio-metabolic transition focusing on socio-economic energy and material use. Broadly speaking, global consumption and production cycles, at their current rates, will inevitably lead to crises, as increased extraction and waste flows cause significant damage to the natural environment (*UNDP, 2015*). An increase in awareness, changes in attitudes, and development of markets and technologies make the "greening" of economic growth more economically attractive and politically acceptable than before. An emphasis on resource flow optimization rather than risk assessment is a key element in the study of industrial ecology (*Ayres, 2002*). This differentiates it from other related studies in environmental science, management or policy.

## 1.2 Literature review

During the last two decades, material and energy flow analysis have emerged as significant methods for tracking the flows of materials and energy, respectively, and for comparing the natural ecosystem and the industrial system. There have been a number of studies using methodological standardization of material flow analysis in industrial, national, regional, and global scales.

Industrial level: Material and energy flows through the UK iron and steel sector for the period from 1994 to 2019 have been evaluated (*Michaelis et al., 2000*). The results indicate that exergy consumption from steel is likely to fall by 15–70% of 1994 levels by 2019 and technological improvement alone does not result insignificant reductions. Italian transportation infrastructure composed of highways, railways, and high-speed railways have also been investigated. Results point out that the most important factors in determining the acceptability of a transportation system are not only the specific fuel consumption and energy and material costs of vehicles, but also the energy and material cost for infrastructure construction as well as the intensity of its use (*Federici et al., 2008*).

National level: The material flow balance of the physical economy and substantial environmental aspects of the Italian economy through an assessment of the mass flow of raw materials and commodities has been performed (*De Marco et al., 2001*). Assessment of the physical economy of China has been conducted for the time series 1990 to 2002 (*Xu et al., 2007*). Results show that the annual material consumption continuously increased except for a slump around 1998. *Gonzales-Martinez and Schandl (2008),* have presented the biophysical perspective of the Mexican economy by accounting for the country's material inputs, and analyzed the dynamics of natural resource usage for given periods. The overall trend of material flow indicators of the Czech Republic have been presented for the period of 1990-2002 (*Kovanda et al., 2010*). It is observed that the accession had quite significant impact on the volume and character of the material flows of Czech Republic. Changes in Japan's metabolism during the industrialization period from 1878 to 2005 has been investigated based on the material flow account (*Krausmann et al., 2011*). During the observed period, the size of Japan' metabolism grew by a factor of 40, and the share of minerals and fossil fuels in domestic material consumption grew more than 90%. For the period 1970-2009 the biological features of the Argentinean economy are examined using a social metabolism approach (*Perez Manrique et al., 2013*). A study on the development of Ukraine's agricultural sector focused on the potential of biofuels has been conducted using data since the early 1990s (*Schaffartzik et al., 2014*). Results show that the attempt to establish a biofuel sector based largely on rapeseed was not successful but has nonetheless left the country at a cross-road in the development of both its economy and its resource use. Complete material flow diagrams of the biomass streams within the Austrian economic system from a meso-scale perspective have been presented for the year 2011 (*Kalt, 2015*). The inland biomass consumption was distributed as follows: 7% human food, 18% raw material, 38% energy and 37% animal feed. Exports primarily consisted of wood products.

Regional level: The development of material consumption of three transition economies: Czech Republic, Hungary and Poland are explored and their material consumption benchmarked against average values for the member states of the European Union that represent a typical market economy (*Kovanda et al., 2008*). Estimation of material use and resource efficiency in the Asia–Pacific region for the period 1970–2005 have been provided (*Schandl et al., 2010*). It was found that the Asia–Pacific has become the single largest user of resources globally, and that the efficiency of resource use in the region decreased over the period of study. Research on historical development of material use in the Bohemia and Moravia-Silesia/Czechoslovakia has been conducted by *Kovanda et al., (2011)* for the period of 1855-2007. Comparative analysis of the level and composition of domestic material use in the EU-15 member states have been investigated for a time series from 1970 to 2001 (*Weisz et al., 2006*). Patterns of change in material use and material efficiency in the former Soviet Union countries have been presented and main drivers of material use have been evaluated through the IPAT model for individual countries (*West et al., 2014*).

Global level: A study on global resource extraction for 1999 by material flow accounting has been conducted to provide benchmark information for political strategies toward sustainable resource management (*Schandl et al., 2006*). First comprehensive quantification of the material basis of the global economy of domestic material extraction in a time series from 1980 to 2002 has been presented for seven world regions (*Behrens et al., 2007*). *Krausmann et al., (2007*) presented a comprehensive assessment of global socioeconomic biomass harvest, use and trade for the year 2000, and found that extraction of used biomass ranged from 0.3 to 2.8 tonnes per hectare per year. Changes in the overall size and composition of global material flows in relation to the global economy, population growth and primary energy consumption have been analyzed for the period 1900 to 2005 (*Krausmann et al., 2009*). The findings show that material use increased at a slower pace than the global economy, but faster than world population. As a consequence, material intensity declined while material use per capita doubled from 4.6 to 10.3 tonnes per capita per year. A long-term global material flow dataset covering material extraction, trade, and consumption for six major geographic and economic country groupings and world regions has been presented for the period 1950 to 2010 (*Schaffartzik et al., 2014*). Regional metabolic rates range from 4.5 tonnes per capita in Sub-Saharan Africa to 14.8 tones per capita in the Western Industrial grouping.

# 1.3 Research area - Uzbekistan

*Geographical condition:* Uzbekistan is the third largest of the five post-communist countries in Central Asia (Figure 1). It is one of only two countries in the world that are doubly landlocked. A doubly landlocked country is one which is surrounded by landlocked countries. Total area is 448000 square meters which comprised of 80% lowland and 20 % mountain areas. With desert occupying so much land, and few lakes, water is scarce and unevenly distributed. Main sources of water are the Amu Darya, with headwaters in Tajikistan, and Syr Darya, which originates in the Kyrgyz Republic. Both are used extensively for irrigation, with some of their outflow diverted to artificial canals to expand the area of land in agricultural production. Less than 10% of its territory is intensively cultivated irrigated land in river valleys and oases (*SCS, 2011*).


**Figure 1. Geographical location of research area–Uzbekistan (*ADB, 2010 amended*)**

*Socio-Economic development:* Since it gained independence in 1991, Uzbekistan chose to transform its centrally planned economy into a market economy, undertaking this, in a gradual and socially focused manner. The government expended efforts to protect its population against shocks caused by a very fast transition into a market economy, owing to the rapid liberalization processes. Since independence the government policy model was based on an incremental transformation of the economy. Variation trend in Uzbekistan's GDP during two decades are differing significantly. Since 1991 to 2001, a facet of this period was that it contained political and economic instability with GDP and per capita GDP an AGR of 2.8% and 1.1%, respectively. The second decade in 2002-2012 GDP and per capita GDP significantly increased with an AGR of 9.9% and 8.3%, respectively (Figure 2) (*CIA World Fact Book, 2013*). In this period GDP growth was enhanced by expanded industrial base and the growth in commodity exports. The country's main natural resources used for earning foreign currency are natural gas, gold and cotton. Uzbekistan's main share sectors of GDP are industry (24%), agriculture (17%) and services (53%) (*SCS, 2012*) (Figure 3). While agricultural output in absolute numbers increased, the share of agriculture in GDP decreased from 22% in 1991 to 17% in 2012, and the proportion of industry increased from 18% to 24%. The share of the service sector rose from 46% in 1991 to 53% in 2012.

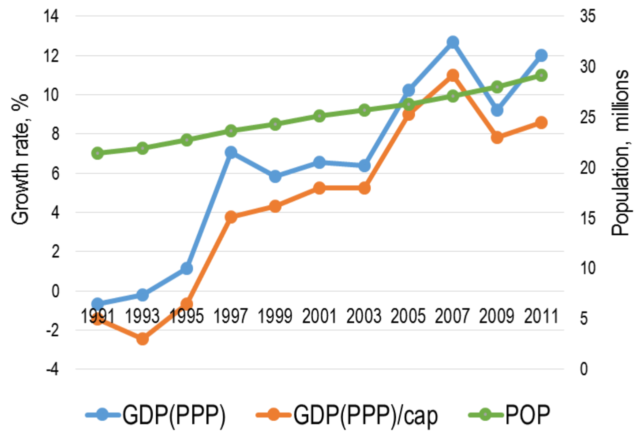



**Figure 2. Purchasing-power-parity Gross Domestic Product GDP, GDP per capita, Population in Uzbekistan (1991-2012).**

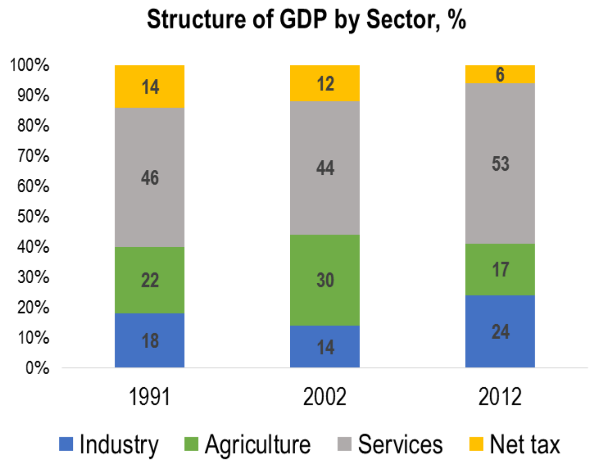



**Figure 3. Structural Changes in the Economy of Uzbekistan (1991-2012)**

Since the 2000s, the government has tried to maintain a delicate balance between the goal of reducing poverty and generating investment resources needed to develop industry and infrastructure as the basis of sustainable economic growth and employment generation. Between 2002 and 2012, the volume of investments into the economy increased 6.4 times – from USD 2.0 to USD 12.1 billion (*SCS, 2012*). Large-scale investments concentrated in basic industries (fuel and energy sector, ferrous and nonferrous metallurgy, light and food industry) which were essential for accelerating economic growth, boosting exports and creating the foundations for sustainable welfare improvement in the medium and long run. In industrial sector mining is a major driver of Uzbekistan's economy. Large mineral reserves, notably of copper, gold, fossil fuels, uranium are important sources of country's revenue. The country is progressively increasing its industrial base, with the food processing, machinery, chemicals and automotive sector playing principal roles. Due to government effort the number of fibers processed textile fabrics has increased which is caused to growth of domestic cotton consumption in the recent years. Uzbekistan is the only central Asia country that produces motor vehicles on a large scale. External demand on vehicles is gradually increased during second decade of independency. Uzbekistan's agricultural sector is still largely dominated by cotton farming, although production has dropped by 35 % since 1991. Uzbekistan is now the world's fifth largest cotton exporter and sixth largest producer.

*Policy implementations*: The economic development strategy implemented so far by Uzbekistan is largely based on import substitution and export promotion. By means of import substitution policies, the government intended to promote the industrialization of the country and secure energy and food self-sufficiency. The government also began to actively promote the privatization of major enterprises in a number of key economic sectors. Special programs for support of small and medium enterprises were adopted in this period, and the privatization of large companies in the basic sectors of the economy were started through promoting privatization of state-owned enterprises and their sale to foreign investors. Two special economic zones called "tax free zones TFZ" created by the government are intended to attract foreign industrial investments to the country. Increase of export commodities and proceeds of foreign currency indicate needs to liberalization of hard currency market. In 2003 commitments were taken according to the agreement of the international monetary fund to facilitate current account convertibility of the domestic currency. Government policy also puts importance development of infrastructure focused on housing, transportation and public institutions.

*Environmental issues*: The most serious example of the environmental problem is the man-made Aral Sea disaster. By 2007, the sea was only ten percentage of its original size and the nearly fivefold increase in water salinity had killed most its natural flora and fauna. The large-scale use of chemicals for cotton cultivation, inefficient irrigation and poor drainage systems have led to a high filtration of contaminated and salinized water back into the soil. Water pollution from industrial waste and soil contamination from the wide spread use of fertilizers, pesticides and agricultural chemicals are causing many human health disorders. Due to insufficient municipal waste treatment facilities since 1960, municipal wastes are sent to landfill areas that caused to emit a huge hazardous gases and polluting air.

# 1.4 Research objectives

A number of challenges have occurred in Uzbekistan since it gained its independence:

- Separation from Soviet Union since 1991: transition from a central, state-planned to a market based economy
- Increase of industrial based economy, supported by intensive use of domestic natural resources
- Increase of environmental degradation related to soil and water pollution, due to intensive use of land without use of appropriate treatment technologies
- Lack of environmental monitoring and statistical information gathering for better management of biodiversity
- Need for accurate monitoring and control of natural resource capital by integrating environmental, social and economic aspects of the country

The objective of this research is to construct a pilot material flow account, to assess the path of the Uzbekistan economy towards sustainable development using indicators derived from material flow accounting.

The research is guided by the following questions and interests:

- How the Uzbekistan economy is displayed using economy-wide material flow analysis based indicators;
- What are the main driving forces behind the economic growth of the country using the economy-wide material flow analysis perspective;
- What are the main driving forces of domestic material consumption through disaggregated material flow indicators in Uzbekistan;
- What level of Uzbekistan's physical economic performance is depicted by the economy-wide material flow analysis using the associated international comparison;
- Which alternative approaches must be taken for Uzbekistan's future sustainable development?

To address these questions we empirically assess physical dimensions of Uzbekistan's economy using an economy-wide material flow analysis method. Comparative analysis is conducted with other economies to make recommendations for further development of material flow accounting and related policies in Uzbekistan. The 1991-2012 period is relevant to this research because it represents the transition of the economy in Uzbekistan.

# CHAPTER II

# METHODS AND DATA COLLECTION

## 2.1 Material flow analysis

Material Flow Analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time (*Brunner and Rechberger, 2004*). The different types of material flow analysis depend on the primary interest of the analyst. If we are interested in certain substances or materials (because they are related to specific impacts), we may study, for instance, the flows of substances such as heavy metals, chlorine, and carbon or the flow of bulk materials such as wood, energy carries, or plastics. However, if we are interested in the specific effects associated with products, we can perform a life-cycle assessment and study the flows associated with the relevant product chain. By contrast, if we are interested in the metabolic performance of regions or national economies, we should systematically consider all material flows in order to characterize the total throughput of materials and employ the economy-wide MFA method.

MFA builds on earlier concepts of material and energy balancing, as introduced, for example, by *Ayres* (*1978*). The first material flow accounts on the national level have been presented at the beginning of the 1990s for Austria (*Steurer, 1992*) and Japan (*Environment Agency Japan, 1992*). Since then, MFA has been a rapidly growing field of scientific interest and major efforts have been undertaken to harmonize the different methodological approaches developed by different research teams. The Concerted Action "ConAccount" (*Bringezu et al., 1997; Kleijn et al., 1999*), funded by the European Commission, was one of these milestones in the international harmonization of MFA methodologies. The second important cooperation was guided by the World Resources Institute (WRI), bringing together MFA experts for four countries. In their first publication (*Adriaanse et al., 1997*), material inputs of four industrial societies have been assessed and guidelines for resource input indicators have been defined. The second study (*Matthews et al., 2000*) focused on material outflows and introduced emission indicators.

The statistical office of the European Union (Eurostat) published its first methodological guide of MFA and account material flow indicators for EU-15 for the period 1980-1997 (*Eurostat, 2001*). On the basis of better data subsequently obtained from national statistical offices, including new European Union (EU) member states, and again on the basis of a collaboration with the Institute for Social Ecology (SEC) in Vienna and in Wuppertal Institute (WI), a practical guide and an updated series of MFA indicators (1970–2004) were published in the second half of the decade (*Eurostat 2007*). In addition to Eurostat, the Organization for Economic Co-operation and Development (OECD) also became active in material flow research in recent years. It adopted a first council recommendation on MFA in 2004 (*OECD*

*2004*), and with a series of workshops and publications (*OECD 2008a, 2008b, 2008c*) contributed to the advancement and international harmonization of material flow accounting methods.

## 2.1.1 MFA Applications

Material Flow Analysis has been applied as a basic tool in such diverse fields as economics, environmental management, resource management and waste management.

*Resource Management*. There are two kinds of resources: a) natural resources such as minerals, water, air, soil, land and biomass that including plants, animals, and humans; b) human-induced resources such as the anthroposphere as a whole, including materials, energy, knowledge in science and technology, art, and manpower. Resource management comprises the analysis, planning and allocation, exploitation and upgrading of resources. Main objective and important of MFA is for analysis and planning process. It is the basis for modelling resource consumption as well as changes in stocks and therefore it is important in forecasting the scarcity of resources. MFA is helpful in identifying the accumulation and depletion of materials in natural and anthropogenic environments.

*Industrial Ecology.* Search out to optimize the total materials cycle from virgin material to finished material, to component, to product, to waste products and to ultimate disposal is held by applying Industrial Ecology. The system boundaries must be defined in such a way that the pathways of materials are covered from the cradle to the grave. One of the objective in industrial ecology is dematerialization. MFA can be used to check whether a dematerialization concept succeeds in practice.

*Waste Management.* The definition and objectives of waste management have changed over time and are still changing. Waste management takes place at the interface between the anthroposphere and the environment. MFA is helpful in investigating the substance management of recycling/ treatment facilities. MFA can contribute to the design of better products that are more easily recycled or treated once they become obsolete and turn into waste. Waste management is an integral part of economy. Some experts who have experience with MFA suggest that waste management should be replaced by material and resource management.

*Environmental Management & Engineering.* MFA is used in a variety of environmental-engineering and management applications, including environmental-impact statements, remediation of hazardous-waste sites, design of air-pollution control strategies, nutrient management in watersheds, planning of soil-monitoring programs and sewage-sludge management.

## 2.1.2 Economy-wide material flow indicators

Over the past decade, MFA has raised increasing interest as a tool that can provide a more holistic and integrated view of resource and material flows through the economy and that enables the derivation of economy-wide material flow (EW-MFA) indicators, including new indicators reflecting resource productivity or resource use efficiency that could parallel those describing labor productivity (*OECD, 2008*).

EW-MFAs are consistent compilations of the overall material inputs into national economies, the changes of material stock within the economic system and the material outputs to other economies or to the environment (Figure 4). Material inputs from the environment are defined as extraction or movement of natural materials on purpose and by human or human-controlled means. Output flows are defined as material flows released from the economic system to the environment, implying that society loses control over these materials.

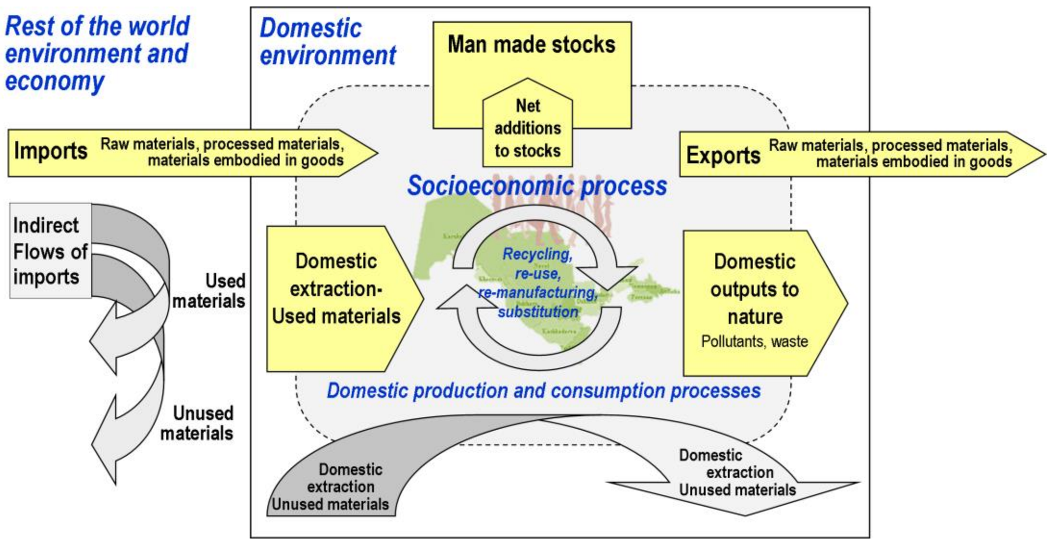



**Figure 4. Material flow categories and EW-MFA main indicators (OECD, 2008 amended)**

A large number of resource-use indicators can be derived from the EW-MFAs, which provide a comprehensive description of the biophysical metabolism of societies (Figure 4). These indicators can be grouped into input, consumption, and output indicators. On the input side, domestic extraction used (DEU) covers the natural materials (excluding water and air) extracted or harvested within the national territory of the economy investigated and further used in economic processing. Unused domestic extraction (UDE) comprises all materials (except water and air) removed from the domestic environment that do not enter the economic system (e.g., mining waste, including overburden). Import (IMP) includes raw materials and semi-manufactured and final goods imported from the rest of the world. Indirect flows associated with Imports (IFI) are the upstream material input flows extracted or harvested from the natural environment in the rest of the world and required to produce the imported goods. Indirect flows associated with Exports (IFE) are the upstream (life-cycle-wide) material input flows required to produce the exported goods

Direct Material Input (DMI) contains all materials that have economic values and are directly used in production and consumption activities. DMI equals the sum of DEU plus IMP (Eq.1).

$$DMI=DEU+IMP \quad \text{(Eq.1)}$$

Total Material Requirement (TMR) equals the sum of DMI and the indirect flows associated with the imports (IFI) and Unused Domestic Extraction (UDE) of the economy (Eq.2).

$$TMR=DMI+IFI+UDE \quad \text{(Eq.2)}$$

The indicator for the consumption group is Domestic Material Consumption (DMC), which measures the total quantity of materials used within an economic system, excluding indirect flows. Thus, DMC is the closest equivalent to aggregate income in the conventional system of national accounts. The DMC is calculated by subtracting exports from DMI (Eq.3).

$$DMC=DMI-EXP \quad \text{(Eq.3)}$$

Total Material Consumption (TMC) is defined as the total material use associated with domestic consumption activities, including indirect flows imported but subtracting export and associated indirect flows. TMC equals TMR minus exports and their associated indirect flows (Eq.4).

$$TMC=TMR-EXP-IFE \quad \text{(Eq.4)}$$

On the output side, the following categories are distinguished as follows: Domestic Processed Output (DPO) equals the flow “outputs to nature,” comprising all outflows of used materials from domestic or foreign origin. Exports (EXP) include raw materials, semi-manufactured and final goods exported to the rest of the world.

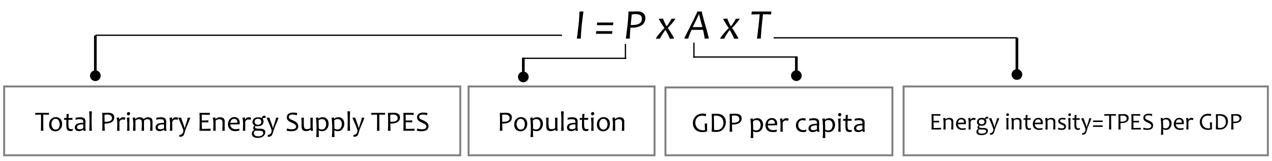
Material accumulation (net addition to stock NAS) is accumulation of material within the economic system in the form of machinery and equipment, buildings and infrastructure, consumer durables and so forth (*Eurostat, 2009*). All EW-MFA based indicators are considered only in physical units by the tonne.

# 2.2 IPAT model

In 1970 by eminent environmentalist Paul Ehrlich and John Holdren the IPAT equation and related formulas were born, along with the modern environmental movement (*Chertow, 2001*). The relationship between technological innovation and environmental impact has been conceptualized mathematically by the IPAT equation. IPAT is an identity simply stating that environmental impact (I) is the product of population (P), affluence (A) and technology (T). IPAT equation can be used to support many different point of view.

$$I = P \times A \times T \quad \text{(Eq.5)}$$

The IPAT equation has also been a source for the development of the literature on energy decomposition analysis, which disaggregated energy intensity and extended and refined the mathematics of IPAT (*Steinberger et al., 2010; Yue et al., 2013; Brizga et al., 2013; Yao et al., 2014;*).

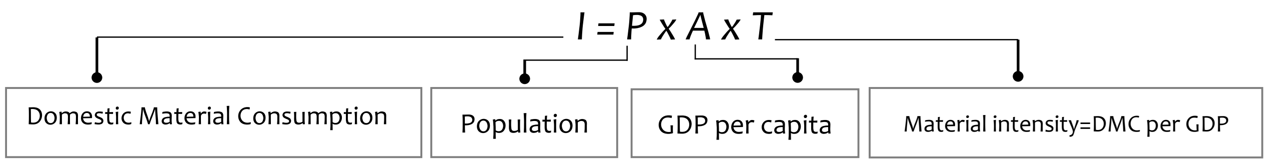



IPAT has played a prominent role, particularly in the Intergovernmental Panel on Climate Change specifically energy-related carbon emission assessment studies.

The notion of (T) had been argued by scientists between expressions of "ecologically faulty technology" by (*Commoner et al., 1971*) and "hope for transformed technology" (*Heaton et al., 1991*). Interpretations by Heaton and colleagues cast the term Technology in IPAT in a very positive light by explaining pollution as the product of population, income levels and the pollution intensity of production. Among these three factors pollution intensity of production shows as the easiest variable to be manipulated. Technology can be used as critical factor for environmental improvement in emerging field of Industrial Ecology. Industrial Ecology examines on the one hand, the environmental impacts of the technological society, and on the other hand the means by which technology can be effective channeled to ward environmental benefit (*Ayres, 2002*).

Number of studies are conducted by employing the IPAT model to evaluate the relationship between MFA-based and socioeconomic indicators to identify key drives of environmental impact (*Xu et al., 2007; Kovanda et al., 2008*). IPAT equation is used to decompose factors responsible for changes in the consumption of materials expressed as

Domestic Material Consumption (DMC) (*Eurostat, 2002*). DMC has been chosen to represent environmental pressure rather than environmental impact.




Here, DMC is a proxy for environmental impact as domestic waste potential. Given that it includes material for intermediary and final consumption impact. Material intensity is used as a proxy for technology. Material intensity expresses the efficiency with which material inputs are transformed into economic output. It refers to technological changes which means improvement in material efficiency.

To better understand the development of material use, analysis key drives independently considered very important (*Schandl et al., 2010; West et al., 2013; West et al., 2014*).

By using the IPAT framework to allocate "blame" for growth or decline we assure that influence of all factors add to 100% is to take the logarithms *Herendeen,* (*1998*):

$$\log I = \log P + \log A + \log T \qquad \text{(Eq.6)}$$

$$\log (I+\Delta I) = \log (P+\Delta P) + \log (A+\Delta A) + \log (T+\Delta T) \qquad \text{(Eq.7)}$$

In equation (6) (P), (A), (T) and (I) have changed. Subtracting the equation (6) from (7) the new gives:

$$\log\left(\frac{I+\Delta I}{I}\right) = \log\left(\frac{P+\Delta P}{P}\right) + \log\left(\frac{A+\Delta A}{A}\right) + \log\left(\frac{T+\Delta T}{T}\right) \qquad \text{(Eq.8)}$$

This says that the logs of the factors $(P+\Delta P)/P$, $(A+\Delta A)/A$ and $(T+\Delta T)/T$ add up to the log of $(I+\Delta I)/I$. Because these are now additive, we can determine each factor's fraction of the total.

## 2.3 Classification of materials

We distinguish between four main material categories and ten subcategories, as illustrated in Table 1. For each of the main categories and subcategories, consistent classification is provided, and for each of the ten subcategories, material flow parameters Domestic extraction (DE), Import (IMP), Export (EXP) and other derived MFA-based indicators have been compiled for Uzbekistan for the period 1991-2012.

**Table 1. Classification of material flow categories and subcategories.**

| Main category | Subcategory | Aggregated items |
|---|---|---|
| Fossil Fuels | *1. Natural gas* | Natural gas includes both "associated" and "non-associated" gas. |
| | *2. Crude oil* | Crude oil comprises crude oil, natural gas liquids, refinery feedstocks and additives as well as other hydrocarbons. |
| | *3. Coal* | Coal products comprise lignite, coking coal and other bituminous coal. |
| | | |
| Biomass | 4. Primary Crops:<br>*-cereals*<br>*-vegetables*<br>*-fruits*<br>*-oil bearing crops*<br>*-roots&tubers*<br>*-fibers*<br>*-other crops* | Edible primary crops harvested from croplands |
| | 5. Crop residues used:<br>*-straw*<br>*-sugar and fodder beet leaves* | Used crop residues made available for further socio- economic use |
| | 6. Grazed biomass:<br>*-grazed biomass*<br>*-fodder crops* | Biomass grazed by livestock |
| | 7. Wood:<br>*-timber industrial*<br>*-chemical wood pulp*<br>*-other fiber pulp*<br>*-other paper and paperboard* | Wood and wood pulp, paper materials |
| | | |

| | | |
|---|---|---|
| Construction Minerals | 8. Bulk materials for construction:<br>*-limestone*<br>*-crushed stones*<br>*-gravel and sand*<br>*-clays*<br>*-chalk*<br>*-dolomite*<br>*-gypsum*<br>*-marble*<br>*-other construction products* | Minerals used primarily in construction and mineral-based processed products |
| | | |
| Industrial minerals & Ores | 9. Non-metallic minerals:<br>*-salt*<br>*-sulfur*<br>*-graphite*<br>*-quartz*<br>*-phosphate*<br>*-feldspar*<br>*-fertilizers*<br>*-fluorspar*<br>*-other mining and quarrying* | Non-metallic minerals used predominantly for industrial processes (excluding fossil fuels) |
| | | |
| | 10. Metal Ores:<br>*- iron*<br>*- copper*<br>*- lead*<br>*- zinc*<br>*- silver*<br>*- tungsten*<br>*- gold*<br>*- tin*<br>*- nickel*<br>*- aluminum*<br>*-molybdenum*<br>*- other metal based products* | Metal ores and metal-based products. Domestic extraction of a specific metal ore was calculated by applying a grade factor to data on the primary production of that metal. |
| | | |

## 2.4 Data collection

The methods used for compiling material flow datasets for Republic of Uzbekistan largely consistent with the methodological guidelines set out in *Eurostat* (2011) but include a number of methodological improvement for biomass and construction minerals that have been developed by the author. We complied data set for the material groups of fossil fuels, biomass, construction minerals, industrial minerals and ores during our research. MFA-based indicators calculated for each material groups and data collected as follow:

*Fossil Fuels:* MFA-based indicators of fossil fuels calculated based on data collected from official publications and databases showed in Table 2. Domestic extraction of primary and secondary energy data are taken from the State Committee of the Republic of Uzbekistan on Statistics (*SCS*) (*2012*). Due to lack of information and undeveloped data collection system in Uzbekistan in early independence phase of the country (official communication with head of statistical division of trading in SCS) trade data for primary and secondary energy sources was sourced from International Energy Agency (IEA) (*2012*). For calculation of domestic and foreign hidden flows (unused domestic extraction and indirect flows associated to imports) of fossil fuels, we used the ratios from database of the Wuppertal Institute which reported in technical report of total material flow requirement by European Environment Agency (*EEA, 2001*) (Figure 5). Due to lack of data, domestic and foreign hidden flows of secondary energy is not included in our research. We consider this issue as next step of investigation (Table 2).

**Table 2. Fossil Fuels data collection sources**

| Fossil Fuels | DE | UDE | IMP/EXP | IFI |
|---|---|---|---|---|
| Primary | | | | |
| *Natural gas* | *SCS, 2012* | *OC; EEA, 2001* | *IEA, 2012* | *OC; EEA, 2001* |
| *Crude oil* | *SCS, 2012* | *OC; EEA, 2001* | *IEA, 2012* | *OC; EEA, 2001* |
| *Coal* | *SCS, 2012* | *OC; EEA, 2001* | *IEA, 2012* | *OC; EEA, 2001* |
| Secondary | | | | |
| *LNG* | *SCS, 2012* | *n/a* | *IEA, 2012* | *n/a* |
| *Oil by-product* | *SCS, 2012* | *n/a* | *IEA, 2012* | *n/a* |
| *Electricity* | *SCS, 2012* | *n/a* | *IEA, 2012* | *n/a* |
| Note: "OC" - Own Calculation; "n/a" – Not Available data | | | | |

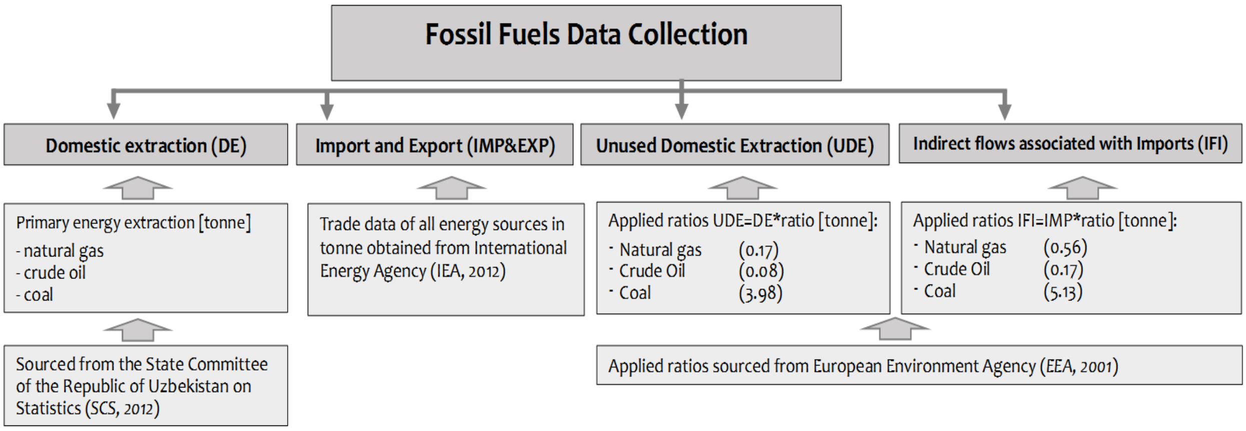



**Figure 5. Fossil fuels data collection flow chart**

*Biomass:* MFA-based indicators of biomass calculated based on data collected from national and international publications and databases presented in Table 3. Absolute values of domestic extraction of primary crops data obtained from national statistics of SCS. Unused biomass derived from cereals are calculated by applying harvest factors and recovery rates reported in the literature of *Wirsenius, (2000)* (Figure 6). Ratios for calculation of unused biomass of vegetables, fruits and roots&tubers are sourced from Sustainable Europe Research Institute (SERI, 2005). Ratios applied for calculation of crop residues derived from cereals, oil bearing crops and fibers used were taken from the sources of the Wirsenius, 2000 and the Agricultural Research Center (*ARC, 2012*) in Uzbekistan under the Ministry of Agriculture and Water Resources of the Republic of Uzbekistan (Figure 7).

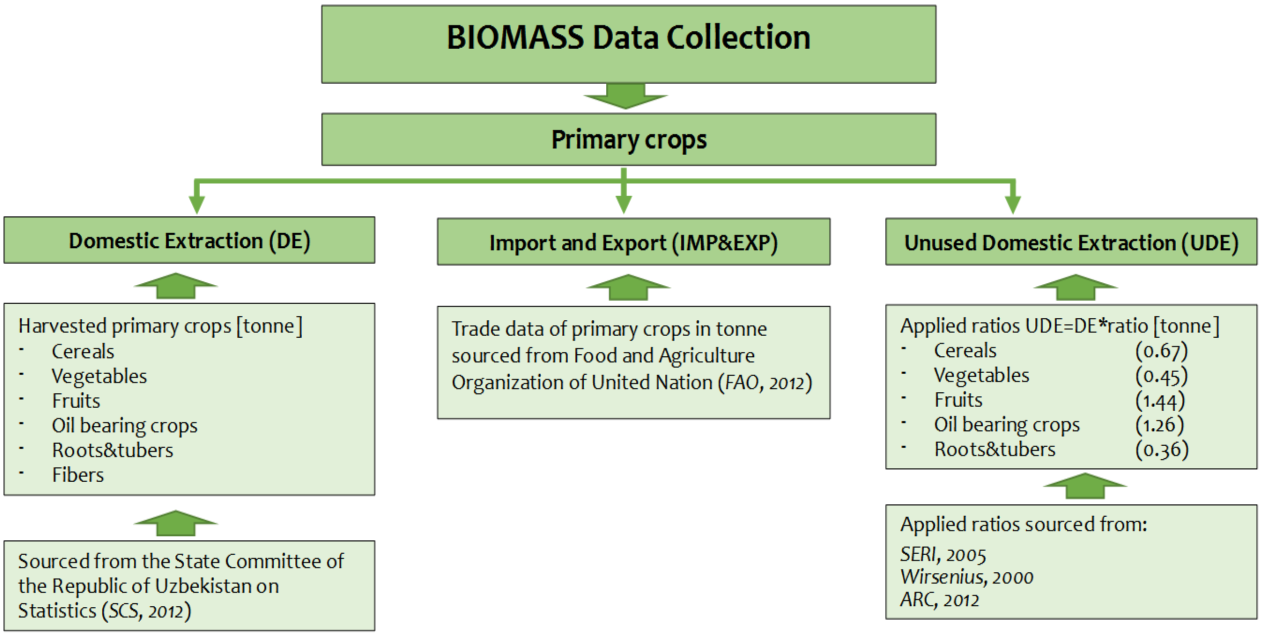



**Figure 6. Primary crops data collection flow chart**

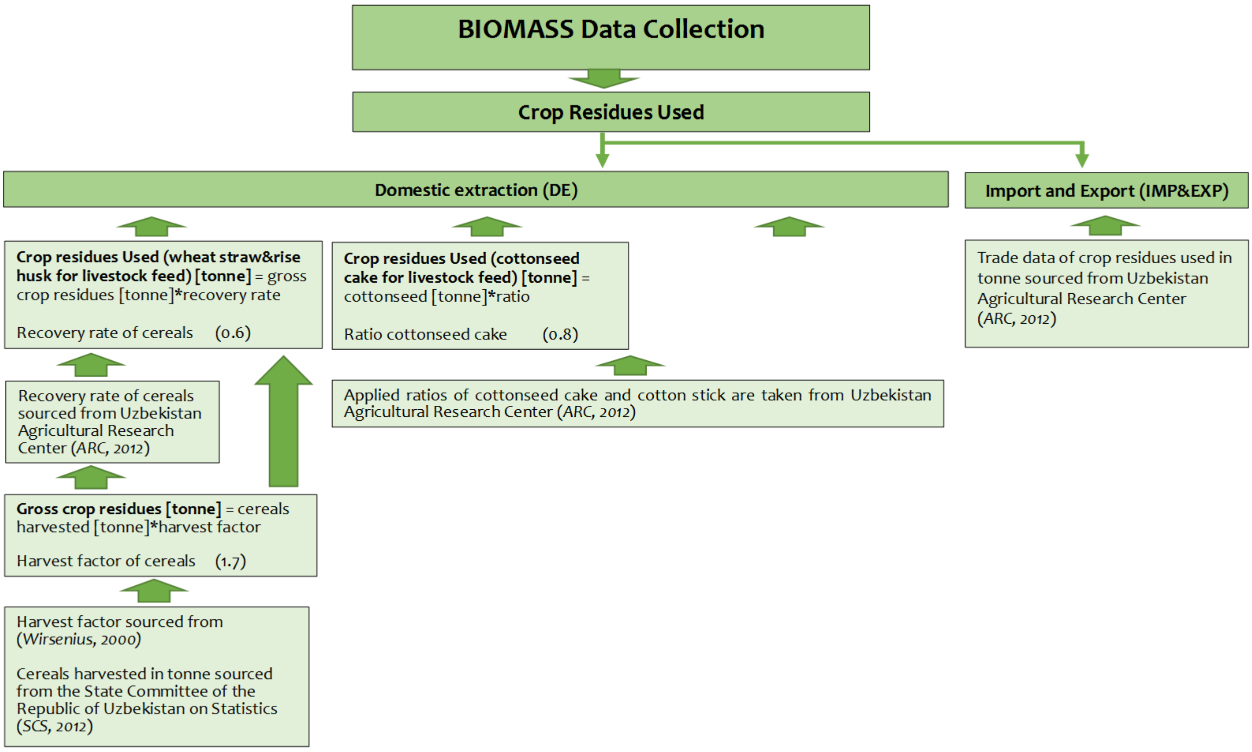



**Figure 7. Crop residues used data collection flow chart**

For calculation of grazed biomass we took data of fodder crops, number of livestock and coefficients of average annual intake in tonne per head of livestock species from SCS and ARC for the period of study (Figure 8).

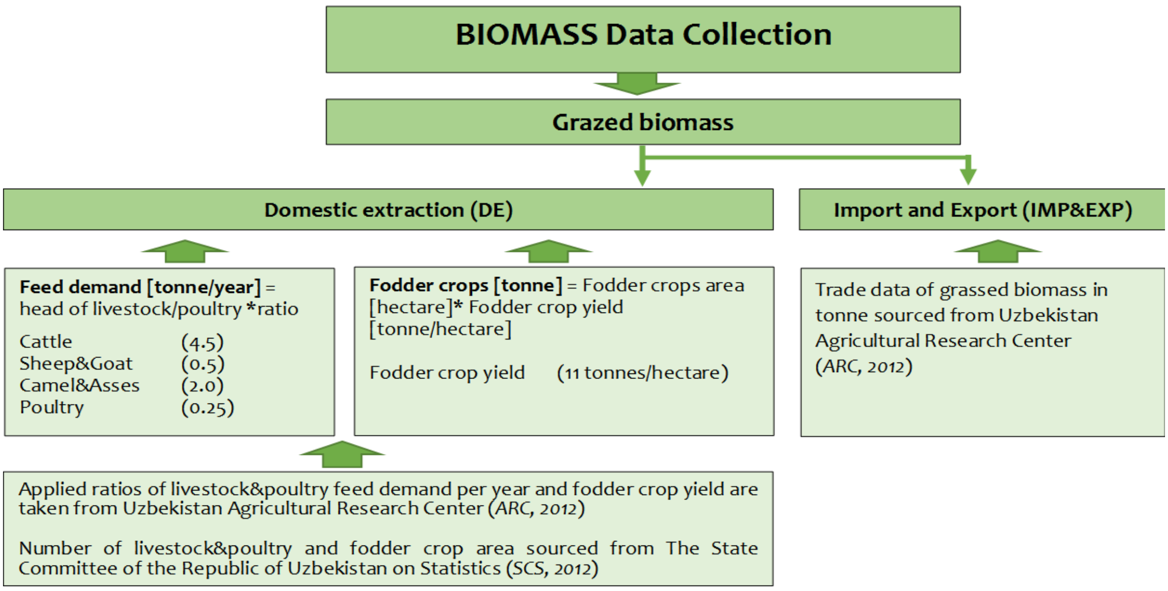



**Figure 8. Grazed biomass data collection flow chart**

DE of wood products were calculated by applying default densities supplied in (*Eurostat 2009*). Trade data of primary crops and all data of wood products obtained from international statistics source of Food and Agriculture Organization of United Nation (*FAO, 2012*) (Figure 9). Trade data of crop residues used and grazed biomass are taken from a source of ARC for the period of study (Table 3).

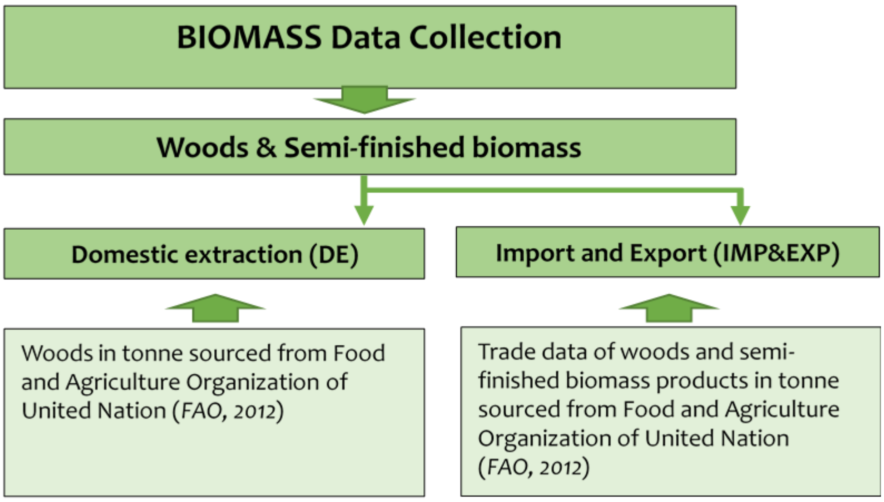



**Figure 9. Wood and Semi-finished biomass products data collection flow chart**

Due to lack of data domestic hidden flows of grazed biomass and wood products and foreign hidden flows of all biomass subcategories (including semi-finished biomass products) are not included in this research. We considered these issues as a next step of investigation (Table 3).

**Table 3. Biomass data collection sources**

| Biomass | DE | UDE | IMP/EXP | IFI |
|---|---|---|---|---|
| *Primary Crops* | *SCS, 2012* | *OC; SERI, 2005; Wirsenius, 2000* | *FAO, 2012* | *n/a* |
| *Crop residues Used* | *OC; ARC, 2012; Wirsenius, 2000* | - | *ARC, 2012* | *n/a* |
| *Grazed biomass* | *OC; SCS; ARC, 2012* | *n/a* | *ARC, 2012* | *n/a* |
| *Wood* | *FAO, 2012* | *n/a* | *FAO, 2012* | *n/a* |
| *Semi-finished biomass product* | - | - | *FAO, 2012* | *n/a* |

Note: "OC" - Own Calculation; "n/a" – Not Available data

*Construction Minerals:* Data of construction minerals for calculation MFA indicators are compiled from different approaches and official publications and organizations (Table 4). Domestic extraction of non-metallic minerals are obtained from the State Committee of the Republic of Uzbekistan on Geology and Mineral Resources (UzGeolCom). Other bulk materials used in construction are calculated by several evaluation methods as follows:

1) Estimation of limestone extraction calculated through cement production by ratio 1:1.4. Meaning that, 1.4 tonnes of limestone are required to produce 1 tonne of cement (*Eurostat, 2007*). Data of cement production and trade data was collected from SCS (*SCS, 2012*). 2) Estimation of sand and gravel used for concrete production by assuming that the 6.5 tonnes of construction aggregates to 1 tonne of cement used in making concrete (*Krausmann et al., 2009*). 3) For road foundation we estimated sand and gravel used for automobile asphalt road and railway construction. For bitumen production we estimated sand and gravel used for asphalt production by a ratio of 1:20 (*Krausmann et al., 2009*). For one kilometer of railway construction we estimated an average of 7000 tonnes per kilometer, for highway construction 3000 tonnes per kilometer of sand and gravel utilized according the multi-method evaluation method by *Federici et al.* (*2008*). Data of railway extensions for each year was taken from the (*SCS, 2012*). 4) In order to account for other construction materials: bricks, sand and gravel used for other purposes than concrete and asphalt production we proceed as follow: We assumed an average area of one private house in Uzbekistan as 200 square meter and estimate that an average amount of construction materials (brick, sand and gravel) used for construction of one private dwelling as 2.5 tonnes per square meter. Previously estimated sand and gravel used for concrete production assumed that this concrete production used only multi-level housing or other public building construction. It should be noted that in Uzbekistan private houses are constructed by fired-bricks rather than concrete. We estimated clay, sand and gravel used for one private house by assuming 2.5 tonnes per square meter. These figures are based on standards and regulations of a residential construction company "Kurilish" in Uzbekistan. Annual growth rates of private dwellings for each year were taken from Uzbekistan Statistical on People's Living Conditions Yearbook (Figure 10).

Trade data of construction minerals including semi-finished products were requested through an official letter (SCS, N01/3-01-26-236) to the SCS during the research. Requested data was provided only for the period 2000-2012, due to undeveloped data collection system in early independence phase of the country (official communication with head of statistical division of trading). Domestic and foreign hidden flows of construction minerals calculated by using ratios sourced by European Environment Agency (*EEA, 2001*). It should be noted that due to lack of data foreign hidden flows of semi-finished product of construction minerals are not included in our study. We considered this issue as a next step of investigation.

## Table 4. Construction Minerals data collection sources

| Construction minerals (CM) | DE | UDE | IMP/EXP | IFI |
|---|---|---|---|---|
| *Non-metallic minerals* | *UzGeolCom, 2012* | *OC; EEA, 2001* | *SCS, 2012* | *OC; EEA, 2001* |
| *Bulk materials used for:* | | | | |
| - *cement production* | *OC; Eurostat, 2007; SCS, 2012* | *OC; EEA, 2001* | *SCS, 2012* | *OC; EEA, 2001* |
| - *concrete production* | *OC; Eurostat, 2007; SCS, 2012* | *OC; EEA, 2001* | *SCS, 2012* | *OC; EEA, 2001* |
| - *road construction* | *OC; Krausmann, 2009; SCS, 2012* | *OC; EEA, 2001* | - | *OC; EEA, 2001* |
| - *dwelling construction* | *OC; SCS, 2012* | *OC; EEA, 2001* | - | *OC; EEA, 2001* |
| *Semi-finished products* | - | - | *SCS, 2012* | *n/a* |
| Note: "OC" - Own Calculation; "n/a" – Not Available data | | | | |

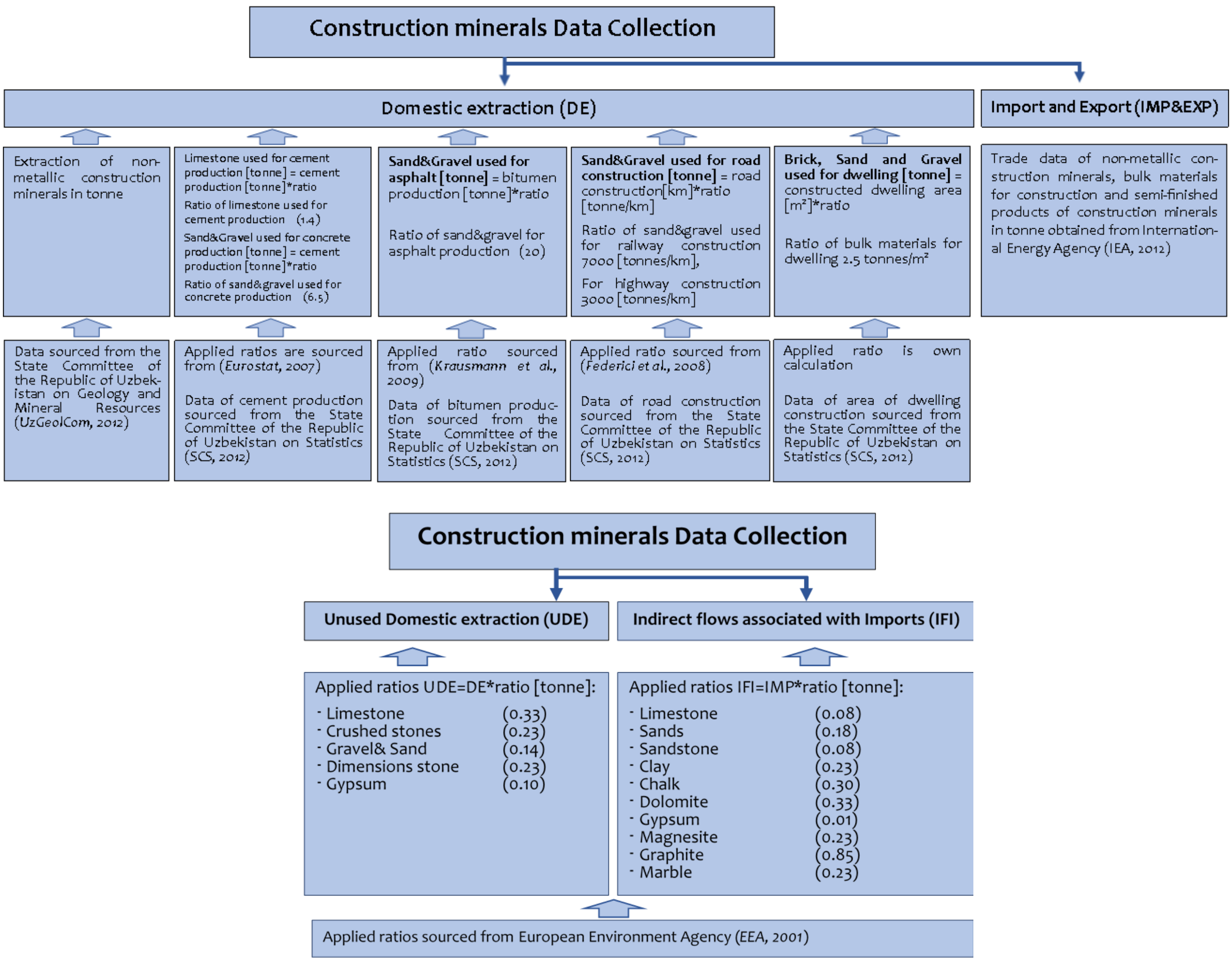



**Figure 10. Construction minerals data collection flow chart**

*Industrial Minerals&Ores:* Used sources for calculation of MFA-based indicators of industrial minerals is shown in Table 5. Domestic extraction of industrial minerals obtained from UzGeolCom during our research investigation survey. Data of domestic extraction of metal ores were not available due to a confidential record of the Republic of Uzbekistan. For that reason, in our study we used a data of domestic extraction metal ores sourced from database of the Commonwealth Scientific and Industrial Research Organization (CSIRO) (*CSIRO, 2012*).

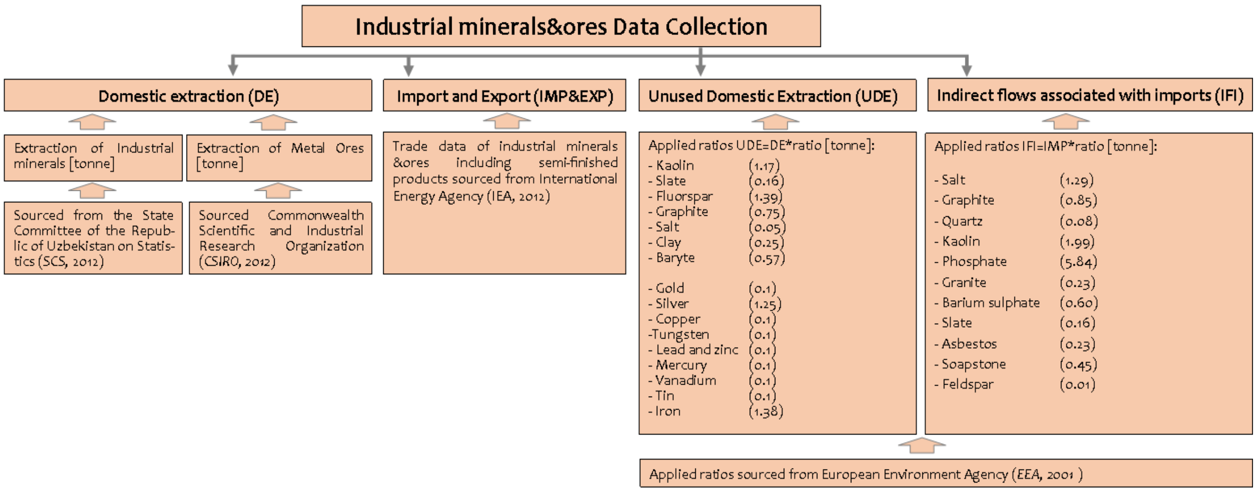



**Figure 11. Industrial minerals&ores data collection flow chart**

Trade data of industrial minerals and ores including semi-finished products were requested through an official letter (SCS, N01/3-01-26-236) to the SCS during the research. Ore minerals such as gold, silver, and molybdenum trade data were not available due a confidential record of the Republic of Uzbekistan. Domestic and foreign hidden flows of industrial minerals and metal ores calculated by applying ratios sourced by *Eurostat*, (*2001*) (Figure 11). It should be noted that foreign hidden flows of semi-finished product of industrial minerals and ores are not included in our study. We considered this issue as a next step of investigation.

**Table 5. Industrial minerals and ores data collection sources**

| Industrial minerals & Metal Ores | DE | UDE | IMP/EXP | IFI |
|---|---|---|---|---|
| *Industrial Minerals* | *UzGeolCom, 2012* | *OC; Eurostat, 2001* | *SCS, 2012* | *OC; Eurostat, 2001* |
| *Metal ores* | *CSIRO, 2012* | *OC; Eurostat, 2001* | *SCS, 2012* | *OC; Eurostat, 2001* |
| *Semi-finished products* | - | - | *SCS, 2012* | *n/a* |
| Note: “OC” - Own Calculation; “n/a” – Not Available data | | | | |

List of collaborative organizations used for data and information collection in our research:

- The State Committee of the Republic of Uzbekistan on Statistics
- The Stock Company "Uzbekenergo", Ministry of Energy of the Republic of Uzbekistan
- The State Committee of the Republic of Uzbekistan on Geology and Mineral Resources
- Ministry of Agriculture and Water Resources of the Republic of Uzbekistan
- Agricultural Research Center, Uzbekistan
- International Energy Agency of the Republic of Uzbekistan
- The Food and Agriculture Organization of the United Nations
- The Commonwealth Scientific and Industrial Research Organization, Australia
- The United States Geological Survey, USA
- European Commission on Statistics, Luxembourg
- Wuppertal Institute for Climate, Environment, Energy, Germany
- Sustainable Europe Research Institute, Austria

# 2.5 Reference


1. Adriaanse, A., Bringezu, S., Hamond, A., Moriguchi, Y., Rodenburg, E., Rogich, D., Schütz, H. 1997. Resource Flows: The Material Base of Industrial Economies. World Resource Institute, Washington.
2. Ayres, R. 1978. Resources, Environment and Economics, New York.
3. Ayres, R. U. and Ayres L.W. 2002. A handbook of industrial ecology. MPG Books Ltd, Bodmin, Cornwall. Great Britain.
4. ARC, Agricultural Research Center. 2011. On the cultivation of agricultural crops, maintenance and product technology standard cards. Tashkent. Uzbekistan.
5. Brunner. P.H. and Rechberger, H. 2004. Practical handbook of material flow analysis. CRC Press LLC. United States of America.
6. Bringezu, S., Fischer-Kowalski, M., Klein, R., Palm, V. 1997. Regional and National Material Flow Accounting: From Paradigm to Practice of Sustainability. Leiden.
7. Chertow M.R. 2001. The IPAT Equation and Its Variants. Changing Views of Technology and Environmental Impact. Journal of Industrial Ecology 4(4): 13–29.
8. Commoner, B., M. Corr, and P. J. Stamler. 1971. The causes of pollution. Environment 13(3): 2–19.
9. CSIRO, the Commonwealth Scientific and Industrial Research Organization, Australia. http://www.csiro.au
10. Environment Agency Japan. 1992. Quality of the environment in Japan 1992. Tokyo.
11. Eurostat. 2001. Economy-wide material flow accounts and derived indicators. A methodological guide. Statistical Office of the European Union, Luxembourg.
12. Eurostat. 2002. Material use in the European Union 1980–2000: Indicators and analysis. Prepared by H.Weisz, M. Fischer-Kowalski, C. Amann, N. Eisenmenger, K. Hubacek, and F. Krausmann. Luxembourg: Eurostat, Office for Official Publications of the European Communities.
13. Eurostat 2007. Economy wide material flow accounts and resource productivity: EU15 1970–2004. Luxembourg: European Statistical Office.
14. Eurostat. 2009. Forestry Statistics. European Statistical Office, Luxembourg.
15. FAO, Food and Agriculture Organization of the United Nations. 2012. FAO Statistical Databases. <http://faostat. fao.org>.
16. Federici. M., S. Ulgiati., R. Basosi. 2008. A thermodynamic, environmental and material flow analysis of the Italian highway and railway transport system. Journal of Energy. 33: 760-775.
17. Heaton, G., R. Repetto, and R. Sobin. 1991. Transforming technology: An agenda for environmentally sustainable growth in the 21st century. Washington, DC: World Resources Institute.
18. Herendeen, R.A., 1998. Ecological Numeracy: Quantitative Analysis of Environmental Issues. John Wiley & Sons Inc., New York.
19. International Energy Agency (IEA) autonomous organization. Energy balances statistics. 2012. Energy flow charts.
20. Kovanda, J. and T. Hak. 2008. Changes in material use in transition economies. Journal of Industrial Ecology. 12(5): 721-738.
21. Kleijn, R., Bringezu, S., Fischer-Kowalski, M., Palm, V. 1999. Ecologizing Societal Metabolism. Designing Scenarios for Sustainable Materials Management. CML Report 148, Leiden.
22. Krausmann, F., S. Gingrich., N. Eisenmenger., K.H. Erb., H. Haberl., M.F. Kowalski. 2009. Growth in global material use, GDP and population during the 20th century. Ecological economics. 68: 2696-2705.
23. Matthews, E., Bringezu, S., Fischer-Kowalski, M., Huetller, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., Schuetz, H., van der Voet, E., Weisz, H. 2000. The weight of nations. Material outflows from industrial economies. World Resources Institute, Washington.

24. OECD (Organization for Economic Co-operation and Development). 2004. Recommendation of the council on material flows and resource productivity. Paris: OECD.
25. OECD. 2008a. Measuring material flows and resource productivity: Volume 1. The OECD guide. Paris: OECD.
26. OECD. 2008b. Measuring material flows and resource productivity: Volume 2. The accounting framework. Paris: OECD.
27. OECD. 2008c. Measuring material flows and resource productivity: Volume 3. Inventory of country activities. Paris: OECD.
28. Sustainable Europe Research institute (SERI). 2005. Unused biomass extraction in agriculture, forestry and fishery. Vienna, Austria.
29. Steurer, A. 1992. Stoffstrombilanz Österreich, 1988. Schriftenreihe Soziale Ökologie. No. Band 26. IFF/Abteilung Soziale Ökologie, Wien.
30. Schandl, H. and J. West. 2010. Resource use and resource efficiency in the Asia-Pacific region. Global environmental change. 20: 636-647.
31. SCS, the State Committee of the Republic of Statistics. 2012. Uzbekistan Statistical Yearbook, Tashkent, Uzbekistan.
32. The State Committee of the Republic of Uzbekistan on Geology and Mineral Resources. 2012. Tashkent. Uzbekistan.
33. West, J and H. Schandl. 2013. Material use and material efficiency in Latin America and the Caribbean. Ecological Economy. 94: 19-27.
34. West, J., H. Schandl, F. Krausmann, J. Kovanda, T. Hak. 2014. Patterns of change in material use and material efficiency in the successor states of the former Soviet Union. Ecological Economy. 105: 211-219.
35. Wirsenius, S. 2000. Human use of land and organic materials. Modelling the turnover of biomass in the global food system. Chalmers University, Goteborg, Sweden.
36. Xu, M. and T. Zhang. 2007. Material flows and economic growth in developing China. Journal of Industrial Ecology. 11 (1):121-1-40.

# CHAPTER III

# Assessment of physical economy through economy-wide material flow analysis in developing Uzbekistan

# 3.1 Introduction

Over the past few decades demand for natural resources has accelerated to the extent that it is now widely considered a serious threat to well-functioning economies and societies because of the associated environmental issues such as climate change, biodiversity loss, desertification and ecosystem degradation (*Millennium Ecosystem Assessment, 2005; Wuppertal Institute, 2005; EPA Network, 2006; Stern Review, 2007; WWF, 2012; UNEP, 2013 IPCC, 2014*). The concept of sustainable development concerns not only the natural environment but also human societies and economies (*Xu and Zhang, 2007; MDG, 2010; Griggs et al., 2013*). A main driver of human induced environmental changes has been the growing social or industrial metabolism, that is, the inputs of materials and energy into socio-economic systems and the corresponding outflows of wastes and emissions (*Ayres and Simonis, 1994; Fischer-Kowalski et al., 1998; Haberl et al., 2004; Fischer-Kowalski and Haberl, 2007*). The notion of a socio-metabolic transition is used to describe fundamental changes in socioeconomic energy and material use during industrialization (*Krausmann et al., 2011*). During the last two decades, material and energy flow analysis have emerged as significant methods for tracking the flows of materials and energy, respectively, and for comparing the natural ecosystem and the industrial system (*Erkman, 1997*).

In this study we assess the physical dimensions of Uzbekistan's economy during 1992-2011 y using the economy-wide material flow analysis (EW-MFA) method. This study is considered a first attempt to explore the metabolic performance of the national economy, industrial metabolism, and environmental impacts of Uzbekistan using EW-MFA based indicators.

The research is guided by the following topics and interests: How the Uzbekistan economy is displayed using EW-MFA-based indicators; what main driving forces are behind the economic growth of the country using the EW-MFA perspective; what level of Uzbekistan's physical economic performance is depicted by the EW-MFA using the associated international comparisons; and which alternative approaches must be taken for country's future sustainable development.

To address these questions, firstly we presented and discussed the main EW-MFA indicators for Uzbekistan during the time series for 1992–2011. Secondly, we illustrate the trends of several macro indicators that could draw discussion on the country's future long-term perspectives and macro policy. Finally, conclusions are reached with suggestions and recommendations for further sustainable development of country.

# 3.2 Material input flows

Analysis on the material input flow of the Uzbekistan economy is performed using the main MFA indicators; DMI and TMR. Materials included in DMI indicators are used in production and consumption activities that are of economic value.

Figure 12 shows the absolute measurement of DMI and TMR for Uzbekistan's economy from 1992–2011. The obtained results show DMI and TMR continuously increases from 1992 to 2011 excluding transitory slumps between 1993 and 1995. DMI increased from 226 million tonnes (Mt) in 1992 to 352 Mt in 2011, with an average growth rate (AGR) of 2.79%. TMR grew from 330 to 485 Mt during the same period of study, with an AGR of 2.34%. The continuous increase of both DMI and TMR shows evidence that the high rate of Uzbekistan's economy, which grew by an average of 4% annually (indicated by real GDP and based on constant 1990 US dollar prices), is resulting in an almost continuous increase of material consumption in Uzbekistan. Regarding the transitory slumps in 1993-1995, not only DMI and TMR, but also the subindicators of DE, imports, and domestic HF exhibited the same slumps during this period.

The pattern of variation of DMI and TMR can be divided into three phases, as follows: (I) in 1992-1995, DMI and TMR decreased at respective average rates of -3.45% and -4.27% annually; (II) in 1995-2003, DMI and TMR climbed the scale for a short period and had a decrease back with an average rates 2.67% and 2.83% annually; (III) in 2003-2011, DMI and TMR began to grow again with an AGR of 5.06 % and 4.56% respectively. For the (II) and (III) phases, the annual growth of material inputs was lower than the annual economic growth indicated by GDP.

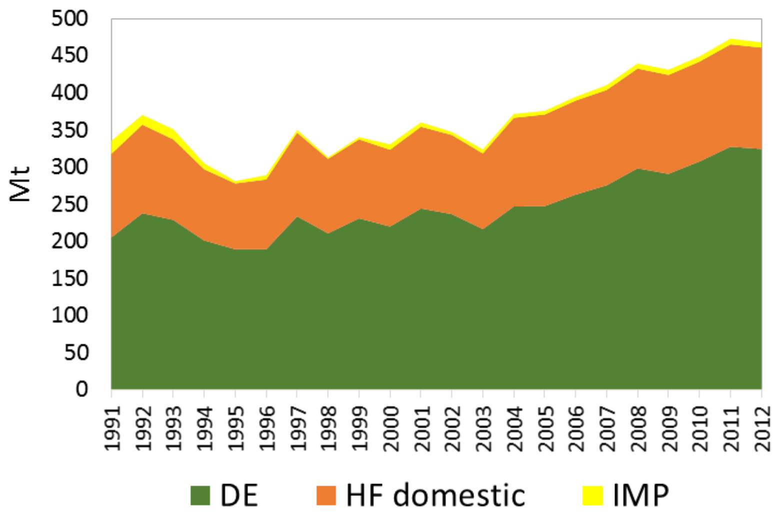



**Figure 12. Input Indicators for Uzbekistan (1992-2011), Million tonnes**

During referenced phases the material requirement per unit of economic growth for Uzbekistan decreased. It can be concluded that the material efficiency of Uzbekistan's economic system improved during either of these phases.

The difference between DMI and TMR indicators results from the so-called "hidden flows" (consisting of unused domestic extraction and indirect flows associated to imports) (*Hammer and Hubacek, 2003*). As shown in Figure 13, hidden flows in 2011 contributed to 30% of TMR. The ratio of TMR to DMI indicated a continual decrease from 1992 to 2011. In 2011, the ratio of TMR to DMI was 1.38, which means 1.38 tonnes of material are completely removed whereas only 1 tonne of material is used in the economic production process. It should be noted, that indirect flows have not been accounted for imported finished products and therefore this figure still represents an underestimation of hidden flows. The progressive decline of the ratio of TMR to DMI shows an increasing development of material efficiency which will be discussed in more detail later.

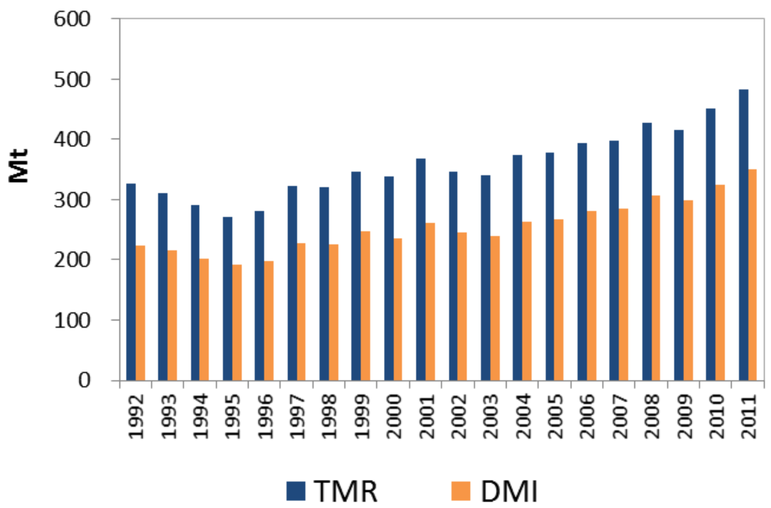



**Figure 13. Relation of TMR and DMI for Uzbekistan (1992-2011), Million tonnes**

Components of DMI and TMR include fossil fuels, industrial minerals and ores, construction minerals, and biomass. Figure 14 depicts the quantitative variation pattern of DMI components. The drawn results show that biomass represented the largest share of the DMI.

Biomass in DMI grew continuously from 77 in 1992 to 112 Mt in 2011 but stayed proportionally in the range of 32% (Figure 15). DMI biomass was compiled by DEU and IMP of biomass subcategories. DEU of biomass is the predominant DMI flow of biomass with a 97% average share. DEU flow of biomass is composed of 60% fodder and grazed biomass for livestock, 20% used crop residues, 19% primary crops and only 1% for forestry biomass. The average growth rate of DEU biomass was 2.53 %, higher than the population average growth rate of 1.78%. The growth in biomass extraction was due to an increase in the amount of biomass grazed for livestock and primary crops production. An average share of biomass import shows only 3% of total DMI and this decreased during the period of study. These figures have been driven by the Uzbekistan's policy of import substitution, focusing on increase of domestic primary food production and achievement self-sufficiency in grain product by 1998 (*Olimov, 2011*).

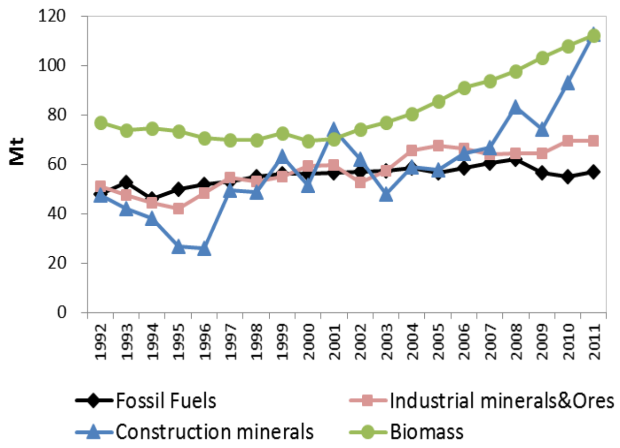



**Figure 14. Direct material input components for Uzbekistan (1992-2011), Mt**

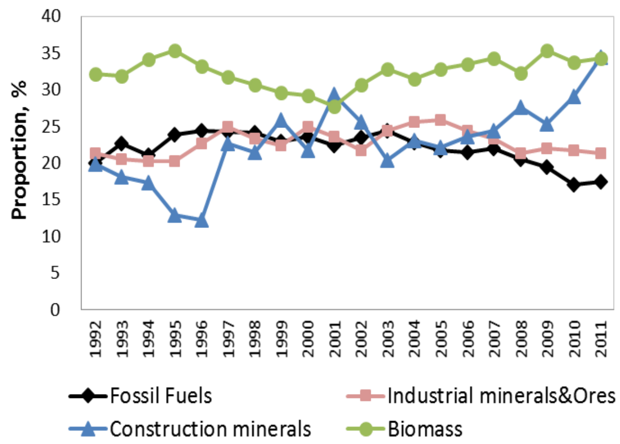



**Figure 15. Proportion of Direct material input components for Uzbekistan (1992-2011), Mt**

The amount of fossil fuels in DMI increased from 48 in 1992 to 57 Mt in 2011 with an AGR of 0.93%. DMI fossil fuels were compiled by DEU and IMP of fossil fuels subcategories (Table 1). DEU flow of fossil fuels is composed by 86% natural gas, 12% petroleum, only 2% for coal products. An average share of DEU and imports in DMI fossil fuels show 96% and 4% during the period of study. Imports of fossil fuels show a significant decrease from 7.7 in 1992 to 0.5 Mt in 2011. These trends have been driven by government measures; energy policy strategic goals adopted by the Government during the early years of independence had been achieved: energy independence and reorientation of the fuel-energy market to achieve priority social goals (*Salikhov, 2004*). The proportion of fossil fuels in DMI continued to increase from 20% in 1992 to 24% in 2003, after which it began to decrease to 16% by 2011.

From 1992 to 2003 construction minerals in DMI increased from 50 to high point of 72 Mt and then decreased back to the initial level in 1992. After 2004, it began to increase again from 60 to 113 Mt by 2011. The proportion of construction minerals in DMI continued to decrease from 22% in 1992 to 21% in 2003. After 2003, it began to be greater than fossil fuels and industrial minerals and ores by equaling the same proportion as biomass of 32% in 2011. Since 2004, both the growing total amount and the growing relative proportion of construction minerals in DMI show their increasingly important role, which is also indicated by the corresponding extremely high growth rate of GDP in the construction industry – an annual average of 12 %. In 1992-2011 industrial minerals in DMI increased from 51 to 70 Mt with an AGR of 1.8% but stayed proportionally in the range of 22%.

For TMR, the variation patterns of each component are almost the same as those for DMI. The difference is that the relative proportion of biomass is lower, industrial minerals and ores are higher than those in DMI. HF of industrial minerals and ores show a higher rate than other components in total HF with a 50 % average share. The TMR per capita for Uzbekistan during 1992–2011, associated with an international comparison is depicted in Figure 16. To conduct the comparison, the following data sources were used. Data for the Czech Republic (1990–2006) *Kovanda et al.,* (*2010*) was used. Data for the United Kingdom (UK) (1992–2010) was taken from *UK Environmental Accounts* (*2012*). For China (1990-2002), we used *Xu and Zhang,* (*2007*). In Uzbekistan, TMR grew from 15 tonnes per capita (t/cap) in 1992 to 17 t/cap in 2011. An average TMR per capita was 14 t/cap with an almost constant trend during the period of study. It can be seen in Figure 16 that the TMR per capita in Uzbekistan is lower than that of all of the referenced countries. We found that, there are two main reasons that may cause lower TMR per capita in Uzbekistan: 1) it is Uzbekistan's policy of import substitution and goals for achieved self-sufficiency in energy and grain production that presented low figures of indirect flows associated imports; 2) it could be described by smaller UDE indicators due to the domination of natural gas in the DEU fossil fuels components (comprising 86%), having a lower ratio calculation than other fossil fuels components of UDE. It should be noted, that HF flows in Uzbekistan contributed to 30 % of TMR while in Czech Republic 70%, in UK 60%, and in China 70% of TMR (*Kovanda et al., 2010; UK Environmental Accounts, 2012; Xu and Zhang, 2007*).

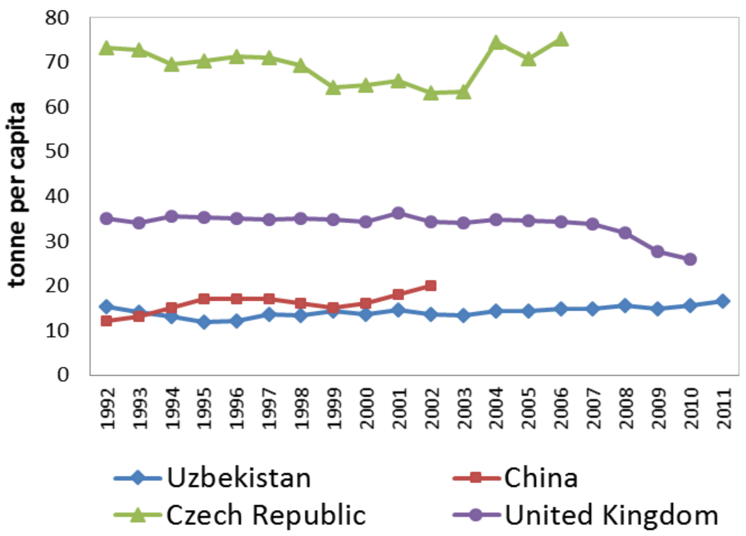



**Figure 16. Total material requirement for Uzbekistan (1992-2011) and International comparison, tonne per capita**

# 3.3 Material consumption

DMC is measured in order to estimate the quantity of material consumed by a national economy, and it is calculated as the sum of total national minerals extracted and imports, less exports. DMC is a crucial indicator of a nation's social metabolism, providing a good measurement – in physical terms – of the intermediate and final consumption of materials in an economy. Between 1992 and 2011, in Uzbekistan, DMC increased from 222 to 337 Mt, with an AGR rate of 2.61%. In relation to the population, DMC per capita had an insignificant change and maintained a stable trend of 10 t/cap average. Figure 17 shows three trends in DMC, (I) an initial decline from 1992 to 1995, (II) from 1995 to 2003 DMC increased for a short period and then decreased back to the initial level before the rise, (III) from 2003 to 2011 overall growth occurred in three consecutive cycles of growth and decline. The initial decline must be understood as corresponding with the economic stagnation and deterioration in in GDP per capita during this period due to political and macroeconomic instability in the early independency of the country.

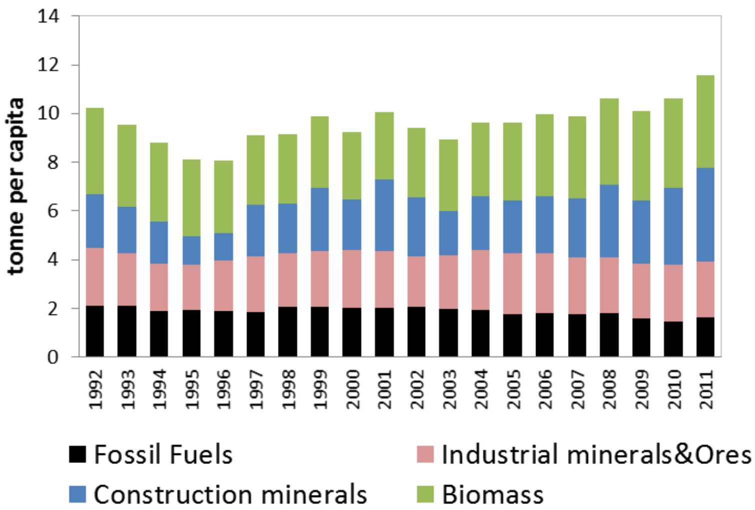



**Figure 17. Domestic material consumption for Uzbekistan (1992-2011), tonne per capita**

As shown in figure 17, biomass is the main resource base of this economy, followed by minerals and fossil fuels. Between 1992 and 2011 the share of biomass DMC increased from 32% to 35%. This could be explained by the increase in crop primary products and grazed biomass for livestock in DEU share and the reduction in exports of primary products during the period of study. In relation to population, biomass DMC per capita increased from 3.5 t/cap in 1992 to 4 t/cap in 2011, with an AGR of 0.4%. Between 1992 and 2011, construction and industrial minerals and ores in DMC stayed proportionally in the range of 24%. Total DMC of both construction and industrial minerals and ores trends increased respectively from 50 to 112 Mt and 51 to 68 Mt with an AGR of 6.1% and 1.7% during the period of study. In 1992-2003, DMC per capita of construction minerals and industrial minerals and ores significantly declined with a negative AGR of -1.49% and -0.63%. From 2003 to 2011, in the context of macroeconomic stability, demand in the construction and industrial minerals and ores recovered, with an average per capita growth rate of 11% and 1% respectively. The rapid increase in demand for minerals was fueled by the state urbanization policy and industrial and innovative development through "growth poles" which involves participation in the construction of rural and urban housing, road construction and the development of regional infrastructure (*Center for Economic Research, 2009*). Government policy also places importance on the development of infrastructure. As the investment push in targeted sectors have induced demands for relevant infrastructure services (*Shadmanov, 2010*).

In contrast, the share of fossil fuels in DMC has decreased from 20% in 1992 to 14% in 2011. This could be explained by the increase in natural gas in the DEU share, which is mostly exported. It should be noted that, Uzbekistan has taken the responsibility of supplying 10 billion cubic meters of natural gas to Russia annually. It can be assumed that the Uzbekistan government will not reduce other exports as it supplies Russia's gas demands by extensively increasing production by a factor of two (*Eshchanov, 2006*). If we compare the DMC of Uzbekistan with western countries such as the UK and Czech Republic, which had 3.8 and 7 tonnes DMC/capita in 2002 (*UK National Statistic, 2012; Kovanda et al., 2008*), Uzbekistan fossil fuels' DMC per capita presents relatively low values, 2 t/cap/year on average for the period 1992-2011. Uzbekistan's energy mix (fossil fuels and hydro power) relies increasingly on natural gas (an efficient energy carrier), which comprised up to 85% of the total supply in 2011 (*BP Statistical Review of World Energy, 2013*). Despite that, the DMC per capita of Uzbekistan was low compared with other industrialized countries. Through consistent pursuit of economic improvement and an energy policy based on the concept of implementing reforms step-by-step, Uzbekistan has been able in a relatively short time, develop its fuel-energy market function sustainably and maintain stability.

# 3.4 Material efficiency from an economic aspect

The main reason for the consumption of materials is their transformation into economic output, which is mostly measured by the aggregated indicator gross domestic product (GDP). If GDP increases, one can expect either an increase in the consumption of materials or an increase in the efficiency of the transformation of materials. Efficiency gains can be related to both the manufacturing technology of particular goods and to the overall technology driving the economic output. This refers to whether the economy is industry oriented or service oriented. In general, industries are more material intensive than services (*Moll and Bringezu, 2005*).

After the economic recession, from 1996 to 2011, GDP showed significant growth in Uzbekistan, with an AGR of 6% (Figure 2). Between 1992 and 2011, GDP share sectors are depicted in Figure 3. In 2011, industry and service sectors made the major contributions to GDP growth. In 1992-2003, the share of the industry decreased from 18% to 14%, which it continued to grow again, from 24% in 2011. As shown in the previous figures, the growth in 2003-2011 periods was fueled by an increase of domestic material production and by supporting and reforming key industrial sectors which was important in the country's stabilization policy (*Shadmanov, 2010*).

In contrast, the agriculture sector proportionally decreased from 22% to 17% during the period of study. This can be explained by the decreasing production of cotton crop, which was the main exported commodity from Uzbekistan (*Stephen MacDonald, 2012*). The service sector had a significant increase from 46% in 1992 to 53% in 2011. The growth in the service sector can be explained by the privatization of state assets, liberalization to induce foreign economic activity, and large-scale investments in the economy. The growth rate of investments has exceeded 18.5% per year on average during 2005–2009, peaking at 28.3% in 2008. The growth of investments was primarily supported by increased foreign investment and loans (*Olimov, 2011*).

Figure 18 shows the trends of GDP per DMI, showing the material efficiency of the economy. GDP per DMI continued to increase from 57 U.S dollar per tonne (USD/t) in 1992 to 88 USD/t in 2011, with an AGR of 2.63%. In comparison, the material efficiency of Uzbekistan is much lower than the average level of EU-15, Czech Republic and China (*Eurostat, 2002; Kovanda et al. 2010; Xu and Zhang, 2007; own calculation*). Increasing GDP per DMI indicates that there must have been some efficiency gains in the transformation of material inputs into economic output. During these two decades the percentage of industry increased to one third and the service sector comprised half of total GDP (Figure 3). Structural reforms related to manufacturing technology of particular goods can be attributed to increase of material efficiency in Uzbekistan. An example, the Uzbekistan primary energy supply is dominated by natural gas with 85% while oil 11%, coal 3% hydro 1% average during the period of study (*IEA, 2011*). This figure shows the more efficient production of energy, as crude oil or natural gas has, in general, higher calorific value per mass unit than coal.

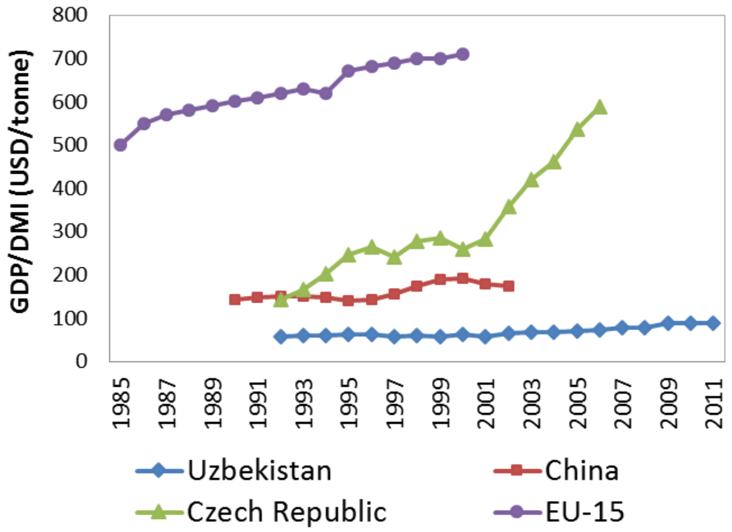



**Figure 18. GDP/DMI for Uzbekistan (1992-2011) and International comparison, USD per tonne**

Another factor for material efficiency growth can be explained by structural and governance reforms, contributing to the opening up of markets, the liberalization of prices and trades, decentralization, massive privatization, and corporate and financial restructuring. These factors played a part in the establishment of a dynamic private sector and a massive flow of foreign direct investment, which attracted advanced technologies and management know-how.

# 3.5 Macro indicators and policy discussion

Figure 19 presents the trends of economic, demographic, and material indicators for Uzbekistan from 1992 to 2011. Material and demographic indictor kept increasing from 1992 to 2011. During the same period, economic indicator GDP shows continuously increase with transitory slump in or after 1993 until 1997. Based on previous discussion, the trends of material input indicators and material consumption for Uzbekistan from 1992 to 2011 can be characterized as three-phased with an initial slump. The three phases are divided by the years 1995 and 2003. In Table 6, it shows an AGR of macro indicators and macro policies that were implemented by the government during the three phases.

**Table 6. EW-MFA based indicators and macro policy implementations in Uzbekistan, average annual growth rate, % (GDP based on 1990 constant US dollar prices)**

| Period of years | IMP | DEU | EXP | DMI | DMC | TMR | GDP | Policy implementation |
|---|---|---|---|---|---|---|---|---|
| 1992-1995 | -19% | -2% | 16% | -3% | -4% | -4% | -2% | Increase domestic production; Import substitution and achieved self-sufficiency of energy and grain products |
| 1995-2003 | 7% | 1% | 3% | 3% | 3% | 3% | 4% | Price and monetary policy: Agreements of the International Monetary Fund (IMF) to facilitate current account convertibility of the domestic currency, 2003. |
| 2003-2011 | 6% | 5% | 6% | 5% | 5% | 5% | 10% | Liberalization to foreign economic activity and faster development of export capacity, large-scale investments into the economy, and gradual improvement of its composition. |

(I) 1992-1995: Initial economic transformations in the country started in an environment when the priority was given to stabilization processes with drastic production decline under the collapse of the centrally-planned economy, loss off of savings and the decreasing income of households. It became clear for policy-makers that the country needed a strong domestic production sector capable of providing basic needs for the population. Therefore, in the stabilization policy, importance was given to domestic material production. The attention was focused on the sectors that determine the development trends of the economy not only in the short term but also in the longer term. These industries included textiles, food, metallurgy, chemicals, and others that could utilize the potential of the rich resource of local raw materials. Structural reforms were targeting tasks of import substitution, export encouragement, and automotive cluster development (*Shadmanov, 2010*). After completing the stabilization stage of reforms, the country proceeded to broader structure transformations, intensive modernization, and active technical and technological modernization of production.

(II) 1995-2003: The Implementation of import-substitution policies by the broad use of direct instruments in economic policies enabled Uzbekistan to achieve certain results, which was facilitated by the fact that exports were dominated by commodities with a low elasticity to exchange rate changes in both the short- and medium-run. The economy of Uzbekistan experienced substantial difficulties in increasing the proceeds of foreign currency due to falling world prices for main export commodities and the 1998 Russian financial crisis (*Olimov, 2011*). In October 2003 commitments were taken according to the Agreements of the International Monetary Fund to facilitate current account convertibility of the domestic currency (*Anderson , 2012*). As a result, in the first few years after the introduction of the regime of "foreign currency rationing", the share of investments goods in the overall imports increased significantly. In 2006, the Fund for the Reconstruction and Development of Uzbekistan was established with its objectives being to ensure the macroeconomic stabilization and utilization of financial resources generated as a result of favorable world prices for the financing of strategically important investment projects in the basic sectors of the economy (*Olimov, 2011*).

(III) 2003–2011: The main driving factors of the economic growth in this period were the high rates of economic activity, largely explained by the liberalization to induce foreign economic activity and faster development of export capacity, large-scale investments in the economy, and a gradual improvement of its composition.

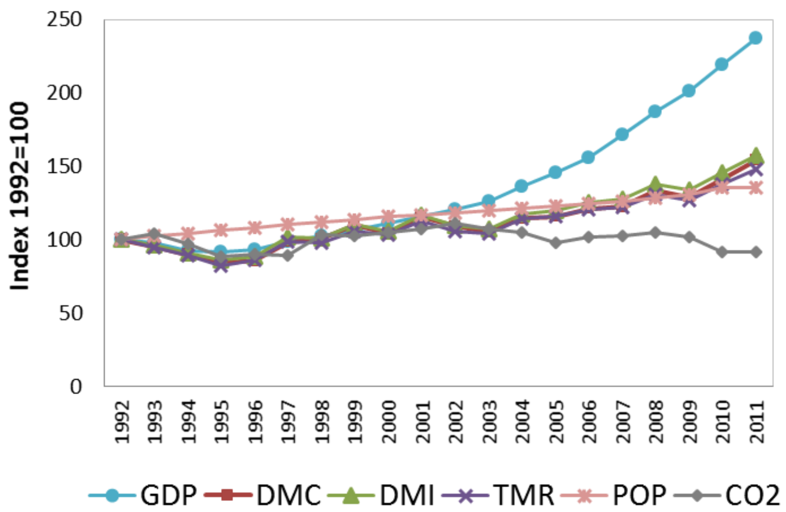



**Figure 19. Relation GDP and DMC with other macro indicators for Uzbekistan (1992-2011)**

The growth of investments was primarily supported by increased foreign investment and loans. In 2009 the share of foreign direct investments and loans in overall investments reached 27.8% against 13.2% in 2005 (SCS).The continuation of the new investments boom is directly related to the modernization and technical overhaul of companies, modernization of fixed assets by the targeted programs for development of the sectors of the economy, construction of industrial infrastructure and social facilities (*Asian Development Bank, 2010*). GDP has increased by a factor of two from 2003 to 2011. The most distinct feature of economic growth achieved in 2003–2011 was the high degree of its stability. As shown in Figure 19, relative decoupling has occurred which indicated that economic indicator (GDP) grows faster than material use (DMC) and other macro indicators grow.

# 3.6 Conclusions

Uzbekistan emerged as an independent state in 1991. Despite many negative shocks in the 1990s, Uzbekistan's policy models chosen by the government have served it reasonably well and were based on a gradual transformation of the economy.

In this paper, the assessment of the physical economy in 1992–2011 for the long-term perspective for Uzbekistan was discussed and analyzed using the EW-MFA method. We further presented the pattern of variations, trends, absolute amounts, components, and efficiencies of the physical material indicators of Uzbekistan's economy. The following conclusions have been made according to obtained results and discussions:

- Input indicators TMR and DMI continue to increase with the growth of domestic material production excluding an initial decline in 1992-1995;
- Trends of TMR, DMI, DMC and material efficiency GDP/DMI indicate lower values than other industrialized countries referenced in the international comparison. Despite that, by consistently pursuing economic improvement and having an energy policy based on the concept of implementing reforms step-by-step, Uzbekistan has been able, in a relatively short time, to avoid economic recession and to develop its fuel-energy market function sustainably and in a stable manner.
- Material efficiency presented that the relationship of GDP to DMI increased in 1992-2011. Related to manufacturing technology of particular goods and structural and governance reforms that would support an increase of material efficiency.
- During (I) and (II) phases, the main driving forces for economic growth were a focus on increase of domestic material production and the intensive modernization of industries. While in (III) phase, economic growth was mainly fueled by development of export capacity and large–scale investment projects.
- Although the economic performance of Uzbekistan shows remarkable success, indicators measuring material inputs (TMR and DMI) and domestic consumption reveal an insignificant increase during 1992–2011. Relative decoupling has occurred which indicated that economic indicator (GDP) grows faster than material use (DMC) and other macro indicators grow. Hence, EW-MFA indicators show that apart from physical dimensions, share of the service sectors: primarily liberalization of foreign economic activities, large-scale investments, and implementation of policy on improvements for education, health, social welfare, transportation and communication has been contributing to the economic growth of the country.

In terms of trade, Uzbekistan's economy has a large trade deficit. Its dependence on export commodities is increasing burdens for the natural environment. Likewise open pit mining, intensive use of agrochemicals, soil degradation and hazardous wastes threaten human health and the environment (*UNDP; SCNP, 2008*). A decoupling can only be seen in relative terms, but the goal of sustainability would make necessary an absolute reduction of material flows. The task would be to find a path of economic development without increasing material flows in absolute terms. Therefore, the rebound effect has to be taken into account. Technological innovations that increase resource efficiency do not automatically lead to decreasing absolute material flows. A sole focus on technology might mean turning a blind eye to environmental impacts and the general state of the environment. Changing lifestyles and their environmental impact will be another important leverage point for environmental policy. By understanding the relationship between economic and technological development, changes in lifestyle, and their related material flows, ways can be found for an absolute decoupling of economic development from material flows and resource use (*Hammer, 2003*).

The advantage of EW-MFA is that the aggregations of the different qualities of material flows provide a possibility of comparing the various physical flows. By contrast, indicators that are too aggregated may conceal the various environmental impacts of different material flows. Therefore, disaggregated exploration of material flows by each industry is critical for detecting influence factors on economic, social and environmental issues.

In the context of data accuracy, in Uzbekistan, the physical datasets related to the physical economy under the current national statistical framework are not well developed. Thus, in future research, more efforts should be devoted to the investigation of more apparent statistical data and the material flow scene.

The study that this paper presents will allow us to advance on to further examine Uzbekistan's economic development. This is the first time such a study, specific to Uzbekistan, has been undertaken. With that in mind we should consider what the next steps should be. In particular, it would be appropriate to consider the next specific area of study that would enhance and add to the value of the work thus far completed. To that end, we would recommend that an assessment of driving forces on environmental impacts and technological development in Uzbekistan would be the most logical next step.

# 3.7Reference


37. Ayres, R. U. 1989. Industrial metabolism. In *Technology and environment,* edited by J. Ausubel and H. Sladovich. Washington, DC: National Academy Press.
38. Ayres, R. U., Simonis, U.E. 1994. Industrial Metabolism: Theory and Policy. In Industrial Metabolism: Restructuring for sustainable development. United Nations University Press, Tokyo, New York, Paris.
39. ADB, Asian Development Bank. 2010. Central Asia - atlas of natural resources.1-211.
40. Anderson, B., Y. Klimov. 2012. Uzbekistan: Trade Regime and Recent Trade Developments. Working paper N.4.
41. BP Statistical Review of World Energy. 2013. London. UK.
42. Bringezu S., H. Schütz. 2001b. Material use indicators for the European Union, 1980-1997. Eurostat Working Papers 2/2001/B/2: Eurostat.
43. Bringezu, Stefan and Helmut Schütz. 2001c. Total Material Requirement of the European Union. Technical Part. Technical Report No 56. Copenhagen: EEA (European Environment Agency).
44. Bringezu, S. and H. Schütz. 2003. Rational Interpretation of Economy-Wide Material Flow Analysis and Derived Indicators. Journal of Industrial Ecology. 7 (2): 43-64.
45. Bringezu, S. and Y. Moriguchi. 2002. Material flow analysis. In A handbook of industrial ecology, edited by Ayres, Robert U. and Ayres, L. W.
46. CER, Center for Economic Research. 2009. Urbanization and industrialization in Uzbekistan: challenges, problems and prospects. Tashkent, Uzbekistan.
47. Daniels, P.L, S. Moore. 2002. Approaches for quantifying the metabolism of physical economies, part I: methodological overview. Journal of Industrial Ecology 5(4): 69–93.
48. de Marco, C., G. Lagioia, and E. P. Mazzacane. 2001. Materials flow analysis of the Italian Economy. Journal of Industrial Ecology. 4 (2): 55-70.
49. EPA, Environment Protection Agencies Network. 2006. Delivering the Sustainable Use of Natural Resources: A Contribution from the Following Members of the Network of Heads of European Environment Protection Agencies on the Thematic Strategy on the Sustainable Use of Natural Resources.
50. Erkman, S. 1997. Industrial ecology: A historical view. Journal of Cleaner Production 5:1–10.
51. Eshchanov, B. 2006. How to meet the future energy needs of Uzbekistan. Master of Science Thesis. Royal Institute of Technology. Industrial Ecology. Stockholm.1-59.
52. Eurostat. 2007b. Economy-wide material flow accounting. A Compilation Guide. European Statistical Office, Luxembourg.
53. Eurostat. 2009. Economy Wide Material Flow Accounts: Compilation Guidelines for reporting to the 2009 Eurostat questionnaire. Version 01. Statistical Office of the European Union. Luxembourg.
54. Eurostat. 2009. Forestry Statistics. European Statistical Office, Luxembourg.
55. Fischer-Kowalski, M. and W. Huttler. 1998. Society's metabolism: The intellectual history of material flow analysis, Part II: 1970–1998. Journal of Industrial Ecology 2(4): 107–137.
56. Fischer-Kowalski, M., H. Haberl. 2007. Socioecological Transitions and Global Change: Trajectories of Social Metabolism and Land Use. Edward Elgar, Cheltenham, UK.
57. Gonzalez-Martinez, A. C., and H. Schandl. 2008. The biophysical perspective of a middle income economy: Material flows in Mexico. Journal of Ecological Economics. 68: 317-327.
58. Griggs, D., Stafford-Smith, M., Gaffney, O., Rockstrom, J., Ohman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., Noble, I., 2013. Policy: sustainable development goals for people and planet. Nature 495 (7441) 305-307.
59. Hammer, M., K. Hubacek. 2003. Material flows and economic development. Material flow analysis of

the Hungarian Economy. International Institute for Applied Systems Analysis. Interim Report. 1-53.
60. Haberl, H., M. Fischer-Kowalski, F. Krausmann, H. Weisz, and V. Winiwarter. 2004. Progress towards sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. Land Use Policy 21(3): 199–213.
61. IPCC, Intergovernmental Panel on Climate Change. 2014. Climate change 2014: Impacts, Adaptation, and Vulnerability. Summary for policy makers. WGII AR5. IPCC, Paris.
62. Krausmann, F., K.H. Erb., S. Gingrich., C. Lauk., H. Haberl. 2008. Global pattern of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. Ecological economics. 65: 471-487.
63. Krausmann, F., S. Gingrich., R. Nourbakhch-Sabet. 2011. The metabolic transition in Japan. A material flow account for the period from 1878 to 2005. Journal of Industrial Ecology. 15(6): 877-891.
64. Kovanda, J. and T. Hak. 2008. Changes in material use in transition economies. Journal of Industrial Ecology. 12(5): 721-738.
65. Kovanda, J., J. Weinzettel. And T. Hak. 2010. Material flow indicators in the Czech Republic in light of the accession to the European Union. Journal of Industrial Ecology. 14(4): 650-665.
66. MacDonald, S. 2012. Economic Policy and Cotton in Uzbekistan. 1-26.
67. Millennium Ecosystem Assessment, 2005. Millennium Ecosystem Assessment Synthesis Report.
68. Moll, S. and S. Bringezu. 2005. Aggregated indicators for resource use and resource productivity. Their meaning, cross-country comparability, and potential driving factors. Copenhagen, Denmark: European Environment Agency.
69. MDG, the Millennium Development Goals, 2010. Report on We can end Poverty. NY.
70. National Bureau of Statistics of Uzbekistan. 2012. Uzbekistan statistical yearbook 1992–2010. Tashkent: Uzbekistan Statistics Press.
71. Nichol, J. 2013. Uzbekistan: Recent developments and U.S. Interests. Congressional Research Service. 1-26.
72. Olimov, U. and Y. Fayzullaev. 2011. Assessing development strategies to achieve the MDGs in the Republic of Uzbekistan. United Nations Department for Social and Economic Affairs. 1-55.
73. Perez Manrique, P.L. et al. 2013. The biophysical performance of Argentina (1970-2009). Journal of Industrial Ecology. 1-15.
74. Shadmanov, E. 2010. Issues of balanced development in Uzbekistan economy. International Cross-Industry Journal. 5 (2): 43-44.
75. Stern, N., 2007. The Economics of Climate Change. The Stern Review. Cambridge University Press, Cambridge.
76. UK, United Kingdom Environmental Accounts. 2012. Agriculture and Environment. Department of Environmental Sustainability, Office for National Statistics. 1-48.
77. United Nations World Commission on Environment and Development. 1987. “Our Common Future”, Brundtland Report.
78. UNEP, United Nations Environment Programm. 2013. Emerging issues in our global environment. UK.
79. UNDP, SCNP, United Nations Development Program and State Committee for Nature Protection of Uzbekistan. 2008. Environmental profile of Uzbekistan based on indicators. Tashkent, Uzbekistan.
80. USGS, United States Geological Survey. 2011. Minerals Information. http://minerals.usgs.gov/minerals/
81. Weisz, H., F. Krausmann, C. Amann, N. Eisenmenger, K.-H. Erb, K. Hubacek, and M. Fischer-Kowalski. 2005b. The physical economy of the European Union: Cross-country comparison and determinants of material consumption. Ecological Economics 58(4): 676–698.
82. Wuppertal Institute. 2005. Fair Future. Begrenzte Ressourcen und globale Gerechtigkeit [Fair Future. Limited Resources and Global Fairness]. Wuppertal Institute for Climate, Environment and Energy. C.H. Beck, München.
83. WWF, UNEP, Global Footprint Network, 2012. Living Planet Report. WWF, Gland, Switzerland.
84. Xu, M. and T. Zhang. 2007. Material flows and economic growth in developing China. Journal of Industrial Ecology. 11 (1):121-1-40.

# CHAPTER IV

# Drivers of Material use during the Transition from State-planned to Market based economy: the case of Uzbekistan 1991-2012

# 4.1 Introduction

By using aggregated economy-wide material flow indicators, Raupova et al. assessed and evaluated the total material input flows of the national economy of Uzbekistan (*Raupova et al., 2014*). However, to identify the drivers of national material use patterns and to assess the progress of decoupling materials consumption from economic growth, a disaggregated material flow analysis approach needs to be applied, as opposed to the highly aggregated indicators used in the previous study (*Weisz et al., 2005*).

In this study we evaluate the socio-metabolic transition of the Republic of Uzbekistan through analysis of the material flow accounts within the economy, by a range of categories and sub categories, for the period 1991-2012 (Table 1).

The disaggregation of material flows during this transition period has been conducted by employing three derived indicators: 1) domestic extraction (DE), 2) domestic material consumption (DMC) and 3) the physical trade balance (PTB). This allows us to monitor the interaction of society with the environment during the socio-economic development of a country. A similar attempt to categorize material flow accounts by material groups has been undertaken previously by the Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Sustainable Europe Research Institution (SERI). However, they did not evaluate their data. The originality of our research is the use of data from the State Committee of the Republic of Uzbekistan on Statistics (SCS) that included the physical trade balance for construction, industrial minerals and ores of material groups which were not included in either of the international data sources mentioned above.

To increase analytical potential of the article, a comparative analysis has been conducted in terms of per capita of DE, PTB and DMC indicators with similar transition economies in Central Asia: Kazakhstan and Turkmenistan (*CSIRO, 2008*); with a European transition economy: the Czech Republic (*Kovanda et al., 2010*) and the industrialized country of the United Kingdom (UK) (*Office for National Statistics UK, 2012*); Japan (*MOE, 2006*); EU-15 average (*Weisz et al., 2005*); World average (*Krausmann et al., 2009*) .

The IPAT model framework is employed to compare the development of material consumption and its relationship with socio-economic indicators during the period of study. In this research we seek the answer to the following questions: How were the disaggregated material flow indicators in Uzbekistan affected during its transition period after independence; How does Uzbekistan, in terms of DE, DMC and PTB, compare to other international economies; Did Uzbekistan take any consideration or action toward a sustainable development path during its transition period?

# 4.2 Domestic material extraction

As the first biophysical indicator, we calculated the Domestic Extraction (DE), which shows the amount of materials extracted within the borders of Uzbekistan. In just over two decades the DE increased from 205.5 in 1991 to 324.6 Mt in 2012 with an AGR of 2.2% (Figure 20). We can identify three distinct periods in the development of the DE over time: 1) 1991-1996, during which all material categories of DE, except for fossil fuels, have declined due to the stagnation of the industrial production system, influenced by deep economic recession of the period; 2) 1996-2003, during which the DE fluctuates somewhat across this eight-year period due to an unstable development of DE of construction minerals; 3) 2003-2012, which saw the development of DE rapidly increase with an AGR of 4.5%, mainly driven by growth in construction minerals (8.8%) and biomass production (6.4%) . In per capita terms, DE has increased from 9.8 to 10.9 tonnes during period of study, a considerable amount if we take into account that average global resource extraction was 10.3 tonnes per capita (t/cap) in 2010 (*Schaffartzik et al. 2014*).

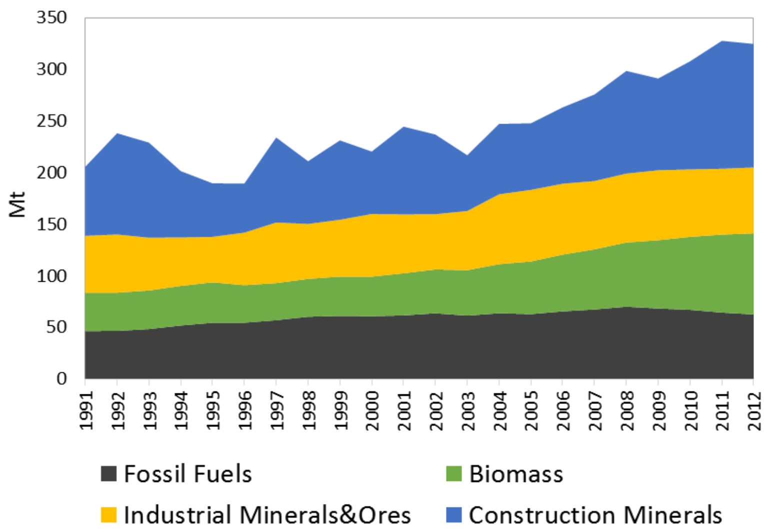



**Figure 20. Domestic extraction components for Uzbekistan (1991-2012), Million tonnes**

# 4.2.1 Fossil fuels

Disaggregated assessment of fossil fuels is important in terms of economic, social and environmental aspects. The share of fossil fuels in the DE in Uzbekistan was 25% on average during the period of study. Domestic development of fossil fuels increased from 46.4 Mt to 62.5 Mt in 1991-2012 with an AGR of 1.4%. The DE of fossil fuels comprises 85% of natural gas, 10% of oil and 5% of coal products, on average (Figure 21).

Natural gas and crude oil extraction have increased with an AGR of 1.8% and 0.8%, respectively, while coal products decreased at an AGR of -2.1% over the period of study. Due to its high sulfur content, the majority of Uzbekistan's natural gas requires processing before it can be consumed. Uzbekistan produces natural gas from 52 domestic fields. Among the two largest gas processing plants are Mubarek Gas Processing Plant, with a capacity of 30 billion cubic meters per year (among the highest in the world), and Shurtan Gas Processing Plant, with a capacity of 20 billion cubic meters per year. At present Uzbekistan is the 11th largest natural gas producer in the world (*Allayev, 2007*).

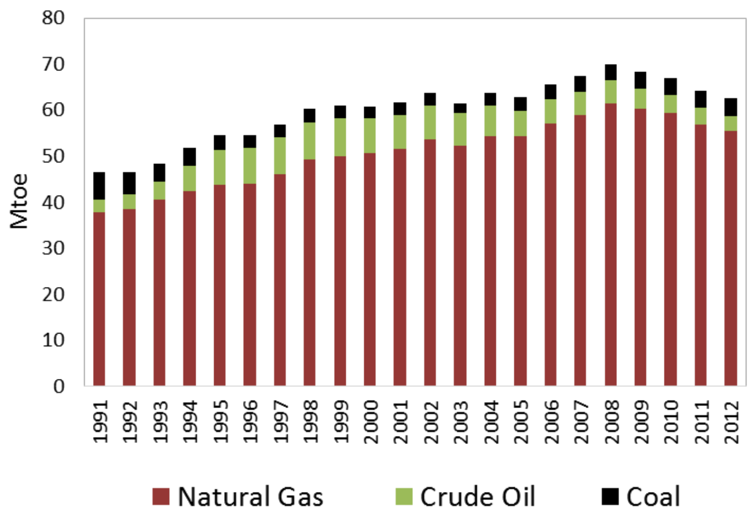



**Figure 21. Fossil fuels extraction for Uzbekistan (1991-2012), Million tonnes**

Crude oil production increased from 2.8 Mt in 1991 to 7.5 Mt in 2000 and thereafter decreased to 3.3 Mt in 2012 due to insufficient oil refineries. There two main oil refineries are operating with a total capacity of 11.2 Mt per year. Uzbekneftegas is a state-owned holding company for Uzbekistan's oil and gas industry.

Coal is produced 3.3 Mt per year on average. The main consumer of coal is the power sector, which accounts for over 85 % of total coal consumption. Coal is also consumed directly by industry, social and utility companies and the residential sector.

# 4.2.2 Biomass

In Uzbekistan about 60 % of total area is agricultural lands including 10% (4.5 million hectare (mln ha)) of arable cropland, of which 4.1 mln ha is irrigated land located mainly in the river valleys of Amu Darya and Syr Darya (Figure 22). The disaggregated assessment of biomass production is crucial as the agricultural sector plays an important role in the total material output of Uzbekistan and helped sustain its socio-economic development during the transition period. About 60% of Uzbekistan's population lives in rural areas, and nearly three million people or 26.3% of the economically active population is employed in agriculture.

Both crop production (55.1% of the total sector output) and livestock production (44.9% of the total sector output) are developed (SCS 2012). Uzbekistan has an arid climate and is noted for its high level of solar radiation, low levels of cloudiness and precipitation, and high evaporation factors, which make irrigation indispensable for agricultural production.

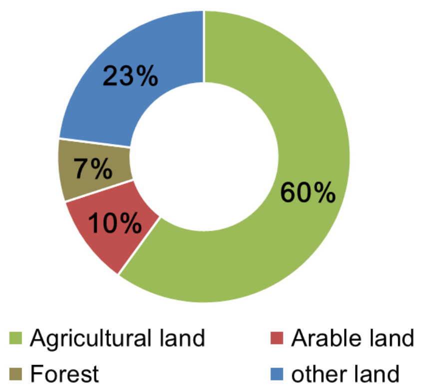



Figure 22. Land distribution in Uzbekistan in (2012), Percentage

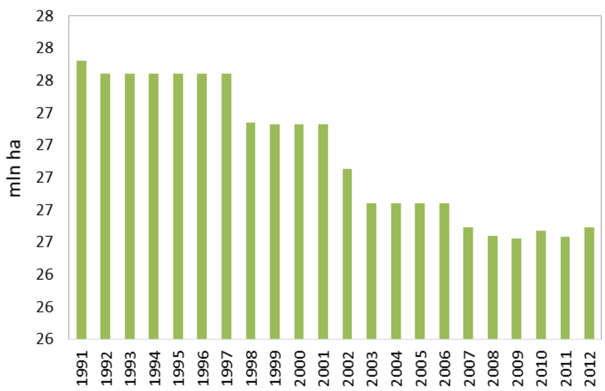



Figure 23. Dynamics of Agricultural land in Uzbekistan (1992-2011), Million hectares

Despite decreased agricultural land area (Figure 23) total biomass extraction in Uzbekistan is increased from 37.0 in 1991 to 78.6 Mt in 2012 with an AGR of 3.6%. It comprises of grazed biomass (50%), primary crops (32%), crop residues (17%) and very small share of wood (<1%), percentages given in average values over the study period (Figure 24). Grazed biomass and primary crops production are represented as the main commodities in biomass extraction with an average share of 82% during period of study.

Primary crops production increased approximately by a factor of two in the study period, from 11.9 Mt in 1991 to 23.8 Mt in 2012 with an AGR of 3.3% (Figure 25). Cereals and vegetables (including roots&tubers) accounted for two thirds (68%) of total production on average in the period of study. In cereal production wheat is dominant with a 90% share on average. Wheat production grew by a factor of three during the period of study. Since 1996 the area of irrigated land for grain has increased by 5 times, yield capacity - 2,3 times, gross harvesting - 4 times (*SCS, 2011*). Higher yields, as well as the expansion of sown areas, accounted for this increase. These were achieved under a policy directed at enabling grain self-sufficiency, which was adopted soon after the disintegration of Union of Soviet Socialist Republics (*Musaev, 2010*). Fibers consist primarily of cotton lint (96%), while jute and cocoon products account for the remaining 4%.

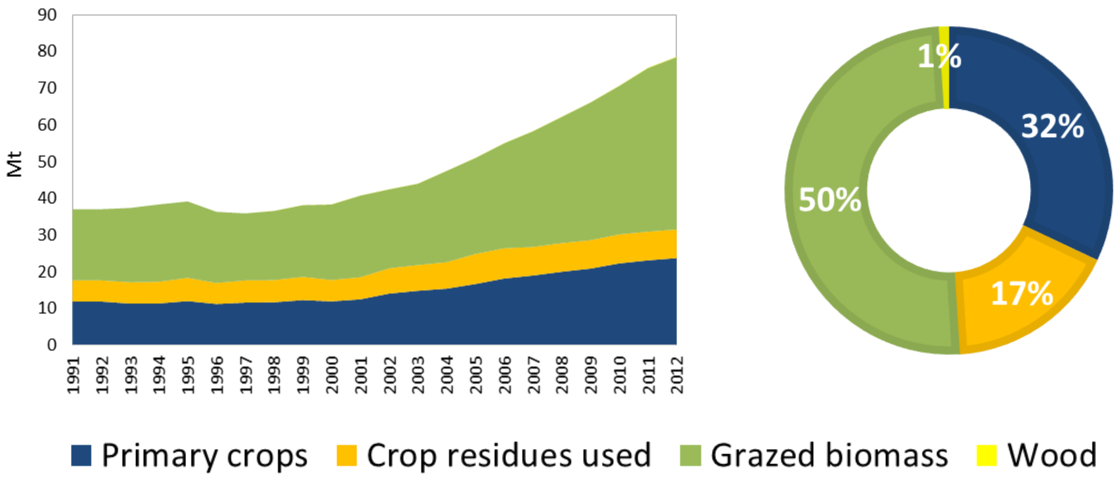



**Figure 24. Biomass extraction for Uzbekistan (1991-2012), Million tonnes and Percentage**

During the period of study, the share of cotton production in primary crops declined from 33% in 1992 to 13% in 2011. Uzbekistan has been experiencing serious problems in cotton production due to poor weather, inadequate production incentives (such as low domestic procurement rates), inadequate inputs, and deteriorating production infrastructure, namely in the area of irrigation (*RSN, 2012*). During the first six years of independence, the area committed to cotton reduced from 2 to 1.4 mln ha and primarily replaced by wheat crops (*Nurbekov, 2006*). Negative rates of assistance for cotton production make grain production relatively more attractive to producers and may play a role in food security policy (*MacDonald, 2012*).

Vegetables comprise of 70% of fresh vegetables, 17% of potatoes and 13% of melons on average. Since independence, the development of the vegetable market was given immediate attention in Uzbekistan. In 1992-2011, production of vegetables increased by a factor of two with an average growth rate of 4.46%. The important vegetables which feed the population in order of their importance are potato, onion, tomato, carrot and white cabbage. In 2011 vegetables show the highest share of 36% in total primary crops in Uzbekistan. Playing an increasingly prevalent role in the production of vegetables output, the private sector fuels positive changes in the national economy as a whole (*Kuo et al., 2006*).

Fruits accounted for 10% of total production on average in 1991-2012. In the second decade of study, the growth of fruit production is accelerated with an average growth rate of

5.14%. This was due to several decrees and acts adopted on further development of fruits vegetable production by the government of Uzbekistan. More than 25,000 hectares (ha) of new orchards were established in Uzbekistan during the second decade of study and an additional 15,000 ha of high-density orchards are planned to be established during 2014. This reflects a gradual transition from inefficient cotton production to other high value crops, which use water and other inputs more efficiently (*Yuldashbaev, 2014*).

Figure 26 shows development of primary crops production (left side) and irrigated arable land use (right side) since 1991. Irrigated arable land areas under grains, vegetables, potatoes and melon have increased while areas under cotton and feed crops have declined over the second decade of study.

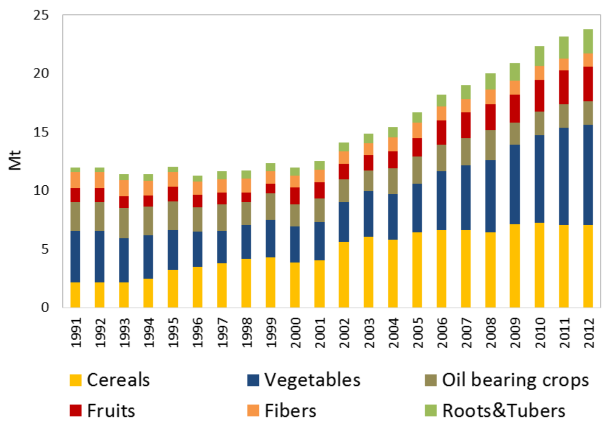



**Figure 25. Primary crops production for Uzbekistan (1991-2012), Million tonnes**

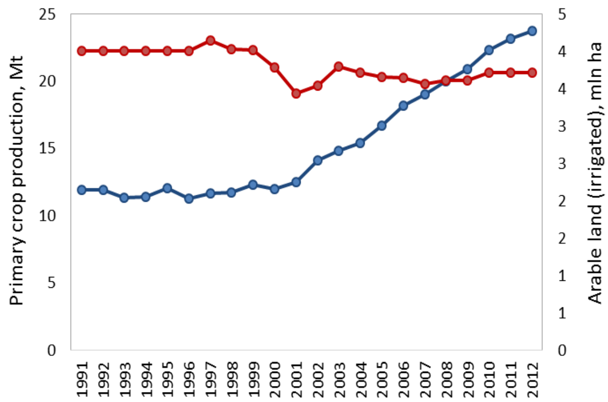



**Figure 26. Development primary crops production and irrigated arable land use in Uzbekistan (1992-2011)**

Despite the decline in irrigated arable land use, production of primary crops has continuously increased during the second decade of study. This can be explained by improved performance of primary crop yields per area, due to technological advances in soil and irrigation system development (*UNDP, 2010*).

Grazed biomass is crucial for livestock production in Uzbekistan. The livestock sector has played a significant role in the socio-economic life of Uzbekistan. During the transition period, while many sectors of the economy of Uzbekistan suffered production fall along with limited opportunities for income generation, only small-scale livestock farming significantly contributed to maintaining the welfare level in rural areas and became an important source of food and income for the rural population. Realizing the importance of ensuring sustainable livestock production development and the urgency of existing problems, the government of Uzbekistan is undertaking a series of measures to reform the sector, including implementing decisions set forth in the Presidential Resolution # 308 dd. 23 March, 2006 on «*Measures for*

*Encouragement of Livestock Expansion in Household Plots, Dehkan and Private Farms»* (*UNDP, 2010*). Grazed biomass increased by a factor of two from 18.4 Mt in 1991 to 44.0 Mt in 2012 with AGR of 4.1% (Figure 24). However, despite continues increase of livestock production, pastures have decreased by 40% as a result of low land productivity and transfer of low-productive and degraded pastures to the State Reserve and Forest Fund (Figure 23) (Figure 27). Declining pasture quality was caused by an increase in cattle herd sizes primarily in the private sector, leading to overgrazing, and unsystematic pasture use such as inobservance of pasture rotation practices (*UNDP, 2010*).

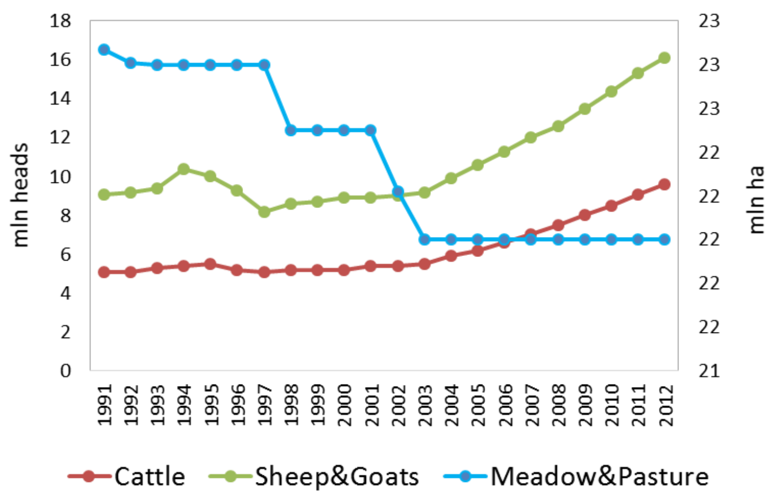



**Figure 27. Development of Livestock and Pasture land use in Uzbekistan (1991-2012)**

Crop residues are mainly derived from cereals as straw and husk (56%), and cotton as cotton seed cake (20%), and are both used as feed for livestock production (*ARC, 2011*). For this reason, to avoid double-counting, we have subtracted the total crop residues from the total grazed biomass, which is used as input for livestock production. Only the residues of cotton stem (24% of crop residues used), which are used as fuel in residential cooking, is accounted for.

Wood products presented a very small share, making up less than one percent of the total primary crops in Uzbekistan. This could be explained by government policy and implemented laws adopted for protection of nature and forest land, which compose only 7% of total area of Uzbekistan (Figure 22) (*FAO, 2012*). In September 4, 2001 the Cabinet of Ministers of the Republic of Uzbekistan issued Resolution 163 "On classification of forests in the Republic of Uzbekistan by protection categories". Logging for industrial purposes is prohibited in the existing natural and semi-natural forests. The need for timber was satisfied by delivery of wood products from Siberia and the Russian Far East (*FAO, 2010*).

## 4.2.3 Minerals

The DE of construction minerals has increased from 66.8 Mt in 1991 to 119.7 Mt in 2012 with an average AGR of 2.8% during the period of study. The proportion of construction minerals in the total DE showed the highest value of 32% an average in 1991-2012. In term of per capita, extraction of construction minerals depicted the highest values and increased from 3.2 in 1991 to 4.0 in 2012.

Uzbekistan is one of the ten leading countries in the world for deposits of gold, uranium, copper and rock and potassium salts. During the years of independence, the Republic of Uzbekistan firmly consolidated its position on the world market of mineral- raw materials resources in multiple directions (*Uzinfoinvest, 2012*). The extraction of industrial minerals and ores increased with an AGR of 0.7% over the study period. The development of DE industrial minerals and ores comprises of metal ores (95%) and industrial minerals (5%), percentages giving an average over the period of study (Figure 28). The extraction of industrial minerals has decreased from 4.4 Mt to 2.3 Mt, while the extraction of metal ores increased from 50.9 Mt to 61.5 Mt in the period 1991-2012. Several adopted laws and regulations have focused on developing the mining industry, aiming to foster mining activities, foreign investment and the access to new technologies, which has increased the capacity of the mining industry to exploit domestic deposits of minerals and ores.

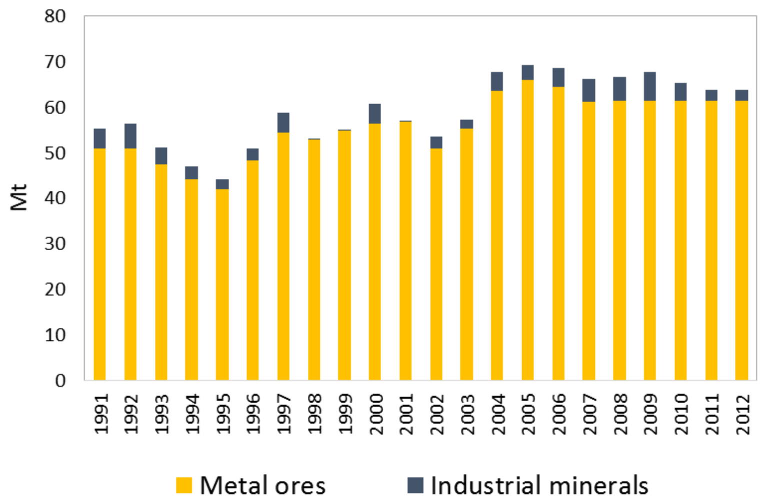



**Figure 28. Domestic extraction of Industrial minerals and ores for Uzbekistan (1991-2012), Million tonnes**

# 4.3 Physical trade balance

After its independence, Uzbekistan built its strategy to strongly focus on decreasing dependence on imports with so called import substitution policies, and promoting exports of domestically produced goods and services. The physical flows of imports and exports for Uzbekistan have dramatically changed during the period of study.

The national import substitution policies and a sharp drop in GDP and production in Uzbekistan drove initial decline in foreign dependency (Figure 29). Performance of GDP per capita and GDP from the industry sector declined with an AGR of -7.2% and -11.6%, respectively, during the same period, 1991-1995 (*Kushnir, 2012*).

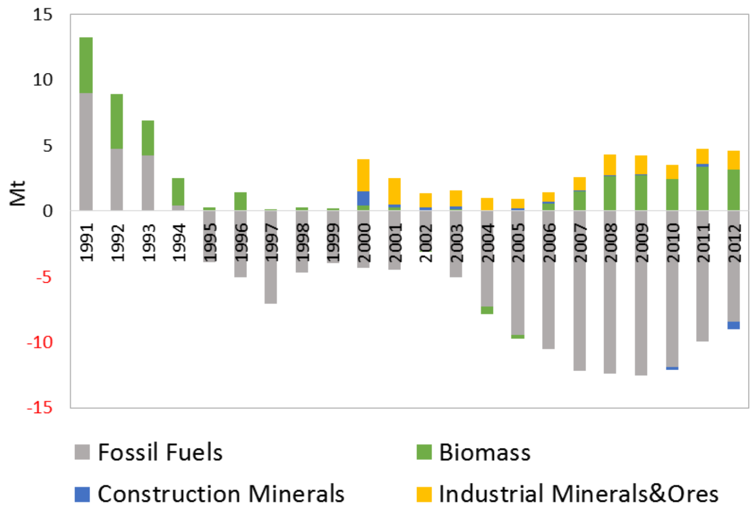



**Figure 29. Physical trade balance for Uzbekistan (1991-2012), Million tonnes**

We divided imports and exports changes in the three phases of the period accompanied with policy implementations and regulations. In 1992-1995 imports rapidly decreased from 17.8 to 3.3 Mt, which was driven by national import-substitution policies. By means of import substitution policies, the Uzbek government intended to promote the industrialization of the country and secure energy and food self-sufficiency (*Bendini, 2013*).By implementing import substitution policies, the government intended to promote the industrialization of the country and secure energy and food self-sufficiency. Export is increased from 4.5 to 6.9 Mt mainly driven by fossil fuels products in 1991-1995 period. Since 1995 Uzbekistan has become a net exporter of fossil fuels. The government program for managing the general economic performance of Uzbekistan, focuses on the fuel-energy market, which forms the foundation for the country's sustainable economic development plan. It sees an increase of the country's export potential as an essential requirement for the economy to function efficiently and meet economic development priorities.

In 1995-2003 imports increased from 3.3 to 5.4 Mt with an AGR of 6.3%. This increase was mainly caused by demand for machinery and chemical products. In this period, the proportion of purchasing machinery and chemical products in total imports (in respect to monetary flow) in Uzbekistan showed the biggest percentage of 41% and 15% average (*SCS, 2011*). The country is progressively increasing its industrial base, with the food processing, machinery, chemicals and automotive sector playing principal roles. Uzbekistan is the only Central Asia country that produces motor vehicles on a large scale (*UZINFORINVEST, 2012*). Export increased from 6.9 to 8.9 Mt with an AGR of 3.3% since 1995 to 2003 period mainly driven by fossil fuels product. Uzbekistan has become a net importer of industrial minerals and ores mainly driven by semi-finished product which account two third of total import in 1995-2003.

An average biomass import comprised of crop biomass (46%), semi-finished biomass product (31%) and wood (23%) in whole period of study. Since 2006, Uzbekistan is a net importer of biomass due to the reduction of cotton exports and the increased demand for food and wood products. Currently, a substantial amount of round wood and wood products is still imported from the Russian Federation (Altai, Siberia) and northern Kazakhstan, although wood imports have reduced considerably since 1990 (*Vildanova, 2006*). During 2003-2012, cotton exports declined in mass by factor of three. The declining trend in cotton exports can be explained by two significant factors: 1) the development of the domestic textile sector, 2) a fall in cotton production due to soil degradation. In the period 2003-2012, imports increased driven by food and wood products increased with an AGR of 12.2% and 15.4%, respectively.

PTB of construction minerals and industrial minerals and ores are a mixed group of materials comprising various types of non-metallic minerals, ores and derived products. Since 2003 exports of construction minerals significantly increased with an AGR of 21.3%, mainly driven by demand for minerals used for construction which accounts for 90% in total exports. A similar trajectory can be seen in Industrial minerals and ores, where exports have increased with an AGR of 8.4% mainly due to non-metallic minerals, which account for 60% of total exports. Uzbekistan was consistently a net importer of industrial minerals and ores in 2003-2012, due to government investment in expanding the private industrial sector, improvement of infrastructure and industrialization development.

In 2003-2012 period export increased from 8.9 to 11.6 Mt with an AGR of 3.0%. In this period export mainly driven by fossil fuels product which accounts 73% in total export in 2012.

# 4.4 Domestic material consumption

DMC is a relevant indicator of a country's social metabolism. In 1992-2012, the DMC of Uzbekistan, increased from 211.9 Mt to 312.9 Mt with an AGR of 1.9% (Figure 30). More than half (58%) of all consumed materials were minerals (including non-metallic minerals for industrial base and construction, and metallic ores) an average in 1991-2012. With a share of 24%, fossil fuels were the second largest fraction of the DMC, while biomass accounted for only 18% on average over the study period. The DMC showed a slightly declining trend between 1991 and 1995 with an AGR of -3.3%. From 1995 to 2003 it fluctuates mainly influenced by minerals. Since 2003, materials consumption increased considerably with an AGR of 4.3%. In terms of per capita consumption, the DMC experienced a slight growth from 10.1 t/cap to 10.4 t/cap over the whole study period.

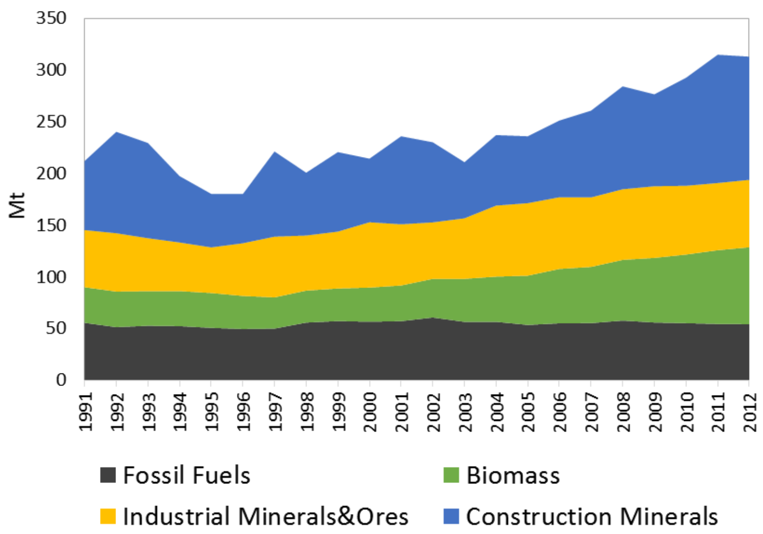



**Figure 30. Domestic material consumption for Uzbekistan (1991-2012), Million tonnes**

Fossil fuels consumption per capita shows a significant decline from 2.6 t/cap in 1991 to 1.8 t/cap in 2012 (Figure 31). This has been influenced by the following factors: a) the AGR of fossil fuels extraction (1.4%) was lower than the population growth rate (1.7%), b) a significant growth in energy exports, with an AGR of 4.5%; c) decreased energy intensity of fossil fuels consumed per GDP with an AGR of -4.0%. However, this decoupling of fossil fuels and minerals consumption per capita could also indicate an overall efficiency gain in the country.

Biomass consumption per capita grew from 1.6 t/cap in 1991 to 2.5 t/cap in 2012. Of the DMC of biomass, 98% is domestically extracted biomass. The imports of biomass only accounts 2% which is mainly dominated by semi-finished biomass products in second decade of study (Figure 31).

Construction minerals consumption per capita grew from 3.2 t/cap in 1991 to 4.0 t/cap in 2012 with an AGR of 1.1% (Figure 31). According to the Center of Economic Research (CER) in Uzbekistan, the rapid increase in demand for minerals was driven by the state urbanization policy and industrial and innovation development through "growth poles", which includes participation in the construction of rural and urban housing, road construction and the development of regional infrastructure (*CER, 2009*). Government policy also places importance on the development of infrastructure. As the investment push in targeted sectors have induced demands for relevant infrastructure services (*Shadmanov, 2010*).

Industrial minerals and ores consumption per capita has decreased from 2.6 t/cap to 2.2 t/cap in 1991-2012 with an AGR of -0.8% (Figure 31). This can be explained by insufficient investments in modernization and upgrading to new technologies in the mining industry. The majority of the mines and metallurgical facilities in Uzbekistan are state owned and have not been privatized, which constrains both foreign and domestic investment.

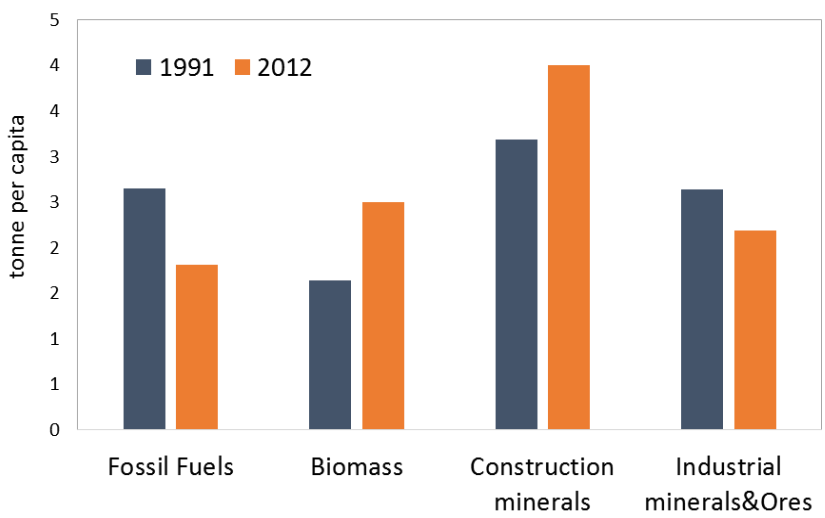



**Figure 31. Development of Domestic material consumption components for Uzbekistan from 1991 to 2012, tonne per capita**

# 4.5 Modified IPAT results

The main reason for the consumption of materials is their transformation into economic output, which is mostly measured by the aggregated indicator gross domestic product (GDP). If GDP increases, one can expect either an increase in the consumption of materials or an increase in the efficiency of the transformation of materials. Efficiency gains can be related to both the manufacturing technology of particular goods and to the overall technology driving the economic output. This refers to whether the economy is industry oriented or service oriented. (*Moll and Bringezu, 2005*).

To analysis the drivers of material use, we apply a variant of the IPAT framework (Equation 5). In order to be able to allocate the contribution to the total growth in material use accounted for by changes in each of the individual drivers of population, affluence of GPD per capita and material intensity of DMC per GDP which total 100%, the IPAT factors have been transformed to logarithmic form (Equation 6, 7, 8). Table 7- presents the change in impact and the key drivers of the DMC during the three distinct periods over two decades in Uzbekistan, as identified in section 4.4. From 1991 to 1995, total materials consumption declined by 15% mainly influenced by affluence (decline in per capita income). Between to 1996 and 2003 period, drives of DMC growth were affluence and technology while population growth contributed lesser extent in a same period. From 2003 to 2012, material consumption grew faster than before, mainly driven by affluence and technological change. Contribution of technology to reducing resource pressure was higher in second and third periods of the study. Over the whole study period, affluence and technology were broadly comparable to increasing population as a driver of DMC growth for most periods. Population growth also contributed to growth of DMC but to a lesser extent.

**Table 7. Major drivers of the change in domestic material consumption for Uzbekistan.**

| Year | ΔI% | ΔI(millions Ton) | ΔLogP% | ΔLogA% | ΔLogT% |
|---|---|---|---|---|---|
| 1991-1995 | -15 | -32 | -52 | 178 | -26 |
| 1996-2003 | 17 | 30 | 62 | 127 | -90 |
| 2003-2012 | 48 | 101 | 39 | 143 | -80 |
| 1991-2012 | 47 | 99 | 91 | 121 | -113 |

# 4.6 International comparison

To increase analytical potential of our study, international comparison analysis conducted in terms of per capita of DE, PTB and DMC indicators and with the same transition economies in Central Asia of Kazakhstan and Turkmenistan, European countries: transition economy of Czech Republic and industrialized country United Kingdom (UK), Japan, EU-15 and World average. IPAT model framework also employed in international comparison analysis to compare the development of material use and its relationship with socioeconomic indicators between comparative economies. Owing to the lack of comparable data sets, we selected the period of 1992-2008.

Data for calculation DE, PTB and DMC indicators for Kazakhstan and Turkmenistan obtained from the Commonwealth Scientific and Industrial Research Organization (*CSIRO, 2008*). The UK data collection sourced by UK Office for National Statistics (*ONS, 2008*). Data for the Czech Republic *Kovanda et al.,* (*2010*) was used. DE and PTB indicators of Japan calculated by data sourced by report of Ministry of Environment in 2006 (MOE, 2006). DMC per capita indicator of Japan obtained from source of *Krausmann et al*., (*2011*). All indicator for EU-15 average taken by sources of *Weisz et al.*, (*2005*) and *Report by European Commission*, (*2010*). World average data sourced by *Krausmann et al*., (*2009*).

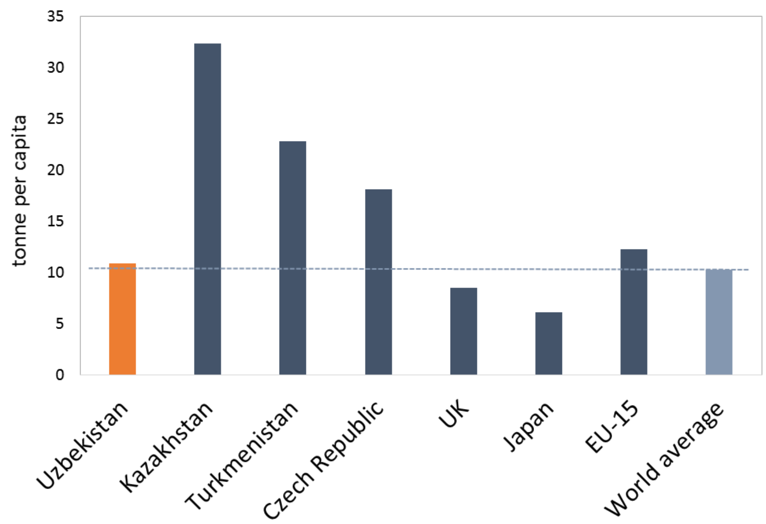



**Figure 32. International comparison of Domestic Extraction, tonne per capita**

Figure 32 depicted that DE/cap of Uzbekistan was three times smaller than Kazakhstan, two times from Turkmenistan. However DE/cap presented higher than industrialized countries of UK and Japan. With EU-15 and world average DE/cap Uzbekistan lays in a same line for the year 2008.

Table 8 presented absolute values of DE/cap of all comparative countries with proportion of material categories of each economies. We found that, proportions of all material components in DE/cap of Uzbekistan was almost same share in 2008 compare other countries. In Central Asia countries the highest share of DE/cap shows fossil fuels (higher than world average) and biomass (lower than world average except Turkmenistan) material categories. In industrialized countries construction minerals depicted the biggest share of DE/cap in 2008 which was much higher than world average.

**Table 8. International comparison of DE/cap (t/cap) and its components share (%), 2008**

| Country | DE/cap | Fossil fules | Biomass | Construction minerals | Industrial minerals&Ores |
|---|---|---|---|---|---|
| **Uzbekistan** | 10.9 | 24% | 21% | 33% | 22% |
| Kazakhstan | 32.4 | 40% | 22% | 14% | 24% |
| Turkmenistan | 22.8 | 54% | 38% | 7% | 1% |
| Czech Republic | 18.1 | 32% | 17% | 50% | 1% |
| UK | 8.5 | 34% | 16% | 48% | 2% |
| Japan | 6.1 | 1% | 10% | 87% | 2% |
| EU-15 | 12.3 | 14% | 30% | 53% | 3% |
| World average | 10.3 | 20% | 32% | 38% | 10% |

In Figure 33, PTB/cap international comparison showed that in Central Asia countries of Uzbekistan, Kazakhstan and Turkmenistan presented as net exporter mainly driven by fossil fuel products. However PTB/cap of Uzbekistan was seven-eight times smaller than Kazakhstan and Turkmenistan in 2008. International comparison of PTB /cap in industrialized countries of UK, Japan and UE-15 depicted as net importer mainly driven by fossil fuel and biomass product in 2008.

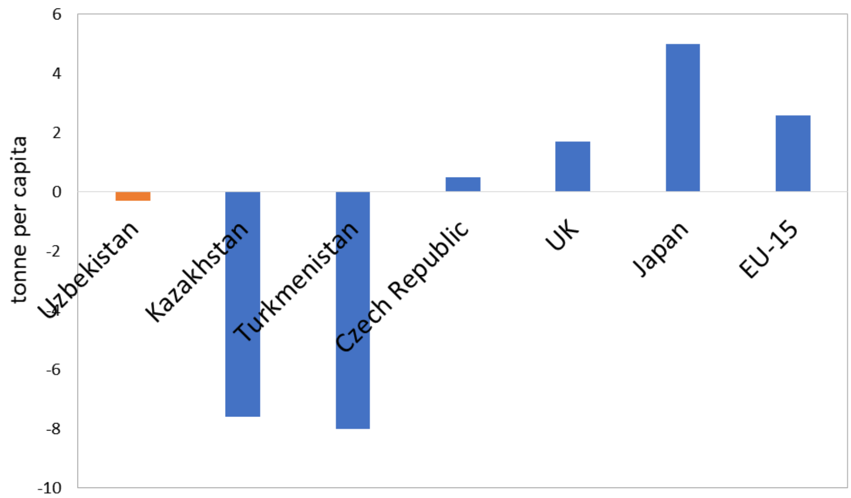



**Figure 33. International comparison of Physical Trade Balance, tonne per capita**

DMC/cap of Uzbekistan showed in a same line with UK and world average while was almost two times smaller than Kazakhstan, 1.5 times than Czech Republic, Japan, EU-15, and Turkmenistan (Figure 34).

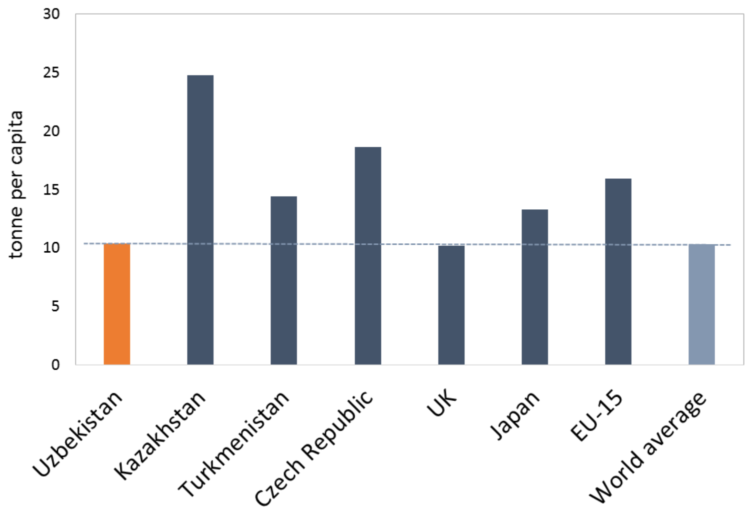



**Figure 34. International comparison of Domestic Material Consumption, tonne per capita**

Table 9 presented absolute values of DMC/cap of all comparative countries with proportion of material categories of each economies. We found that, proportions of all material components in DMC/cap of Uzbekistan and Kazakhstan was almost same share in 2008 compare other countries. Share DMC/cap of fossil fuels and construction minerals in industrialized countries shows higher than world average in 2008.

**Table 9. International comparison of DMC/cap (t/cap) and its components share (%), 2008**

| Country | DMC/cap | Fossil fules | Biomass | Construction minerals | Industrial minerals&Ores |
|---|---|---|---|---|---|
| Uzbekistan | 10.4 | 20% | 21% | 35% | 24% |
| Kazakhstan | 24.8 | 28% | 27% | 19% | 26% |
| Turkmenistan | 14.4 | 28% | 60% | 11% | 1% |
| Czech Republic | 18.6 | 33% | 15% | 45% | 7% |
| UK | 10.2 | 36% | 21% | 39% | 4% |
| Japan | 13.3 | 29% | 12% | 55% | 4% |
| EU-15 | 15.9 | 23% | 25% | 46% | 6% |
| World average | 10.3 | 20% | 32% | 38% | 10% |

Table 10 presented changes in the drivers of DMC for Uzbekistan and comparative countries for period 1992-2008. During first period of study in 1992-1995 in CAC countries DMC declined mainly influenced by affluence. In Czech Republic and UK DMC decline mainly influenced by technological change during same period of time. Between to 1995 and 2003 period, drives of DMC growth in CACs were affluence and technology while population growth contributed lesser extent for Uzbekistan and Turkmenistan in a same period. DMC declined in Czech Republic, UK and Japan mainly influenced by affluence and technological change in 1995-2003 period of study. From 2003 to 2012, material consumption grew faster than before in CACs, mainly driven by affluence and technological change. UK and Japan DMC continue decline mainly influenced by technological change in a same period. Over the whole study period, for all countries (except Turkmenistan) affluence and technology were broadly comparable to increasing population as a driver of DMC growth. For Uzbekistan and Turkmenistan case population growth also contributed to growth of DMC but to a lesser extent (Table 10).

Through the IPAT assessment we found that, in the case of Uzbekistan, it is not enough to improve technological factors to gain material efficiency. Economic growth and an increase in population may have a rebound effect. For this reason we have identified the need to develop a new integrated model on sustainable resource management, which considers both the supply and demand sides of resource use.

**Table 10. Major drivers of the change in DMC, 1992-2008**

| Country | ΔI% | ΔI (Mt) | ΔLogP | ΔLogA | ΔLogT |
|---|---|---|---|---|---|
| (1992-1995) | | | | | |
| Uzbekistan | -25% | -60 | -21% | 51% | 70% |
| Kazakhstan | 42% | -195 | 7% | 52% | 41% |
| Turkmenistan | -7% | -3 | -105% | 451% | -246% |
| Czech Republic | -37% | -112 | 0% | -19% | 119% |
| UK | -1% | -8 | -69% | -757% | 927% |
| Japan | 1% | 11 | 154% | 316% | -370% |
| (1995-2003) | | | | | |
| Uzbekistan | 17% | 31 | 73% | 124% | -98% |
| Kazakhstan | 23% | 64 | -28% | 233% | -105% |
| Turkmenistan | 42% | 16 | 30% | 54% | 16% |
| Czech Republic | -4% | -8 | 29% | -416% | 486% |
| UK | -4% | -30 | -64% | -508% | 672% |
| Japan | -14% | -238 | -12% | -31% | 142% |
| (2003-2008) | | | | | |
| Uzbekistan | 35% | 73 | 22% | 110% | -32% |
| Kazakhstan | 15% | 50 | 36% | 255% | -191% |
| Turkmenistan | 35% | 19 | 19% | 153% | -72% |
| Czech Republic | 8% | 15 | 23% | 296% | -219% |
| UK | -6% | -43 | -54% | -103% | 257% |
| Japan | -7% | -99 | -4% | -87% | 190% |
| (1992-2008) | | | | | |
| Uzbekistan | 18% | 44 | 144% | 224% | -268% |
| Kazakhstan | -17% | -80 | 25% | -301% | 376% |
| Turkmenistan | 79% | 32 | 41% | 56% | 3% |
| Czech Republic | -35% | -105 | -1% | -118% | 220% |
| UK | -11% | -80 | -59% | -308% | 467% |
| Japan | -20% | -326 | -14% | -59% | 173% |

# 4.7 Conclusions

With respect to the three questions asked in the introduction of this paper, the following conclusions can be drawn from the examination of the values and trends of the indicators:

◆ Disaggregated material flow analysis enabled us to evaluate the socio-metabolic transition of Uzbekistan’s economy during the period of 1991-2012 with more depth and across a broader perspective. The development of all of the category material flows was indispensable for the socio-economic development of Uzbekistan during its transition period. DE and DMC patterns in Uzbekistan showed almost the same trend of variation during the period of study. The management of all of the categories of material flow take a major role in two important tasks during Uzbekistan`s development period. The first being the improvement of social aspect issues and the second for the development of the economic performance of the country. National reforms and several adopted policy implementations attributed to trends in material flow variation. In the early years of the first decade established policies and programs on incremental improvement of domestic production, import substitution, the achievement of energy self-sufficiency and grain products implementations could successfully help to avoid economic recession in Uzbekistan and improve social income. In the second decade of transition, liberalization of foreign economic activity, large-scale investments into the economy and the agreement of the International Monetary Fund (IMF) to facilitate current account convertibility of the domestic currency (Anderson, 2012) dramatically increased the physical flow of exports in Uzbekistan. Overall PTB showed that fossil fuel products were the main export commodity during the period of study. A continuous increase of DE and DMC can display good economic performance however, it could also bring several environmental problems such as, in particular, land degradation, air pollution, water shortages and changes in the atmospheric environment of the country.

◆ Comparative analysis depicted that DE and DMC/cap indicators of Uzbekistan demonstrated with fairly sustainable growth rates. In international comparison proportions of material categories in DE/cap were considerably different in all comparative economies for the year 2008. In Uzbekistan, it showed almost the same proportion with the highest share in construction minerals. PTB composition showed that Uzbekistan changed from being a net importer to become a net exporter of fossil fuel products between 1991 and 2012. All industrialized countries depicted net importer while CACs showed a net exporter in 2008. Over all, DMC per capita in Uzbekistan demonstrated a lower and more stable trend among comparative economies during the period of study. However, DMC per capita of each material category in Uzbekistan distributed in an identical level of proportion compared to other countries. This can be explained by the policy model that was chosen by the government which was based on gradual transformation of the economy in a socially oriented manner.

◆ Through IPAT model we found that affluence and technology were broadly comparable to increasing population as a driver of DMC growth. For Uzbekistan case, we found that it is not enough to improve technological factors to gain material efficiency. Economic growth and an increase in population may have a rebound effect.

Economic development and increase of industrial base in Uzbekistan grows resource consumption which consequently processed as waste and pollution to the environment. For that reason, in Uzbekistan serious actions and national regulation has to be taken on the concept of sustainable consumption and production focuses on the sustainable and efficient management of resources at all stages of value chains of goods and services. It encourages the development of processes that use fewer resources and generate less waste, including hazardous substances, while yielding environmental benefits and frequently productivity and economic gains. Based on IPAT analysis economic growth and an increase in population may have a rebound effect. For this reason we have identified the need to develop a new integrated model on sustainable resource management, which considers both the supply and demand sides of resource use.

Finally, we believe that the next stage of investigation, naturally following on from our previous studies, would be a more detailed analysis of environmental issues in Uzbekistan with a particular focus on energy flow and waste assessment. That would enable us to better understand how these important issues affect economic performance and will provide us with sound research which may enable us to influence government policy development in Uzbekistan.

# 4.8 Reference


85. Abdurakhmonov, M. 2003. FDI scenario in Uzbekistan-glancing at the first decade after Independence. Economic journal of Hokkaido University, 32: 183-200. Japan.
86. ADO, Asian Development Outlook 2013: Asia's Energy Challenge. Economic Trends and Prospects in Developing Asia. Manila, Philippines
87. Bendini, R. 2013. Kazakhstan: Selected trade and economic issues. European Union, Belgium.
88. BP Statistical Review of World Energy. 2013. London. UK.
89. CER, Center for Economic Research. 2009. Urbanization and industrialization in Uzbekistan: challenges, problems and prospects. Tashkent, Uzbekistan.
90. CIA, Central Intelligence Agency, 2013. The World Factbook. Washington, D.C. USA.
91. CSIRO, the Commonwealth Scientific and Industrial Research Organization, Australia. http://www.csiro.au
92. David, G. V., A. M. Jaffe, and M. H. Hayes. 2006. Natural gas and Geopolitics. Cambridge University. US. New York.
93. Ehrlich, P.R and J.P.Holdren. 1971. Impact of population growth. Science 171 (3976):1212-1217.
94. EIA, Energy Information Administration. 2013. United Kingdom energy overview. United States.
95. Eshchanov B. 2006. How to meet the future energy needs of Uzbekistan. Master of Science Thesis. Royal Institute of Techonology. Industrial Ecology. Stockholm.1-59.
96. FAO, Food and Agriculture Organization of the United Nations. 2010. Global forest resources assessment, Country report, Uzbekistan. Forestry Department. Rome, Italy.
97. FAO. 2011. FAO Statistical Databases. <http://faostat. fao.org>.
98. FAO/EBRD, Food and Agriculture Organization of the United Nations/European Bank for Reconstruction and Development. 2012. Turkmenistan Agricultural sector review. Country highlights. FAO investment center. Rome, Italy.
99. Kaiser, M.J., and A. G. Pulsipher. 2007. A review of the oil and gas sector in Kazakhstan. Energy Policy. 35: 1300–1314.
100. Krausmann, F., K.H. Erb., S. Gingrich., C. Lauk., H. Haberl. 2008. Global pattern of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. Ecological economics. 65: 471-487.
101. Krausmann, F., S. Gingrich., N. Eisenmenger., K.H. Erb., H. Haberl., M.F. Kowalski. 2009. Growth in global material use, GDP and population during the 20th century. Ecological economics. 68: 2696-2705.
102. Krausmann, F., S. Gingrich., R. Nourbakhch-Sabet. 2011. The metabolic transition in Japan. A material flow account for the period from 1878 to 2005. Journal of Industrial Ecology. 15(6): 877-891.
103. Kovanda, J., J. Weinzettel. And T. Hak. 2010. Material flow indicators in the Czech Republic in light of the accession to the European Union. Journal of Industrial Ecology. 14(4): 650-665.
104. Kovanda, J. and T. Hak. 2008. Changes in material use in transition economies. Journal of Industrial Ecology. 12(5): 721-738.
105. Kuo, C.G., R.F. Mavlyanova, and T.J. Kalb (eds.). 2006. Increasing market-oriented vegetable production in Central Asia and the Caucasus through collaborative research and development. AVRDC publication number 06-679. AVRDC – The World Vegetable Center, Shanhua, Taiwan. 250 pp.
106. Kushnir, I. 2012. World macroeconomic research. Ivan Kushnir`s Research Center. Available at http://kushnirs.org/index.html
107. MacDonald, S. 2012. Economic Policy and Cotton in Uzbekistan. 1-26.
108. Ministry of the Environment Government of Japan. 2006. Material flow analysis in Japan. Tokyo Japan.
109. Moll, S. and S. Bringezu. 2005. Aggregated indicators for resource use and resource productivity. Their meaning, cross-country comparability, and potential driving factors. Copenhagen, Denmark: European Environment Agency.

110. Musaev, D., Y. Yakhshilikov, K. Yusupov. 2010. Food Security in Uzbekistan. UNDP. Tashkent. Uzbekistan.
111. NOS, Office for National Statistics. 2012. Agriculture and Environment. Department of Environmental Sustainability, United Kingdom.
112. Nurbekov, A and R. Paroda. 2006. The Uzbekistan Seed Industry. Focus on Seed Programs. WANA Seed Network Secretariat, Seed Unit, ICARDA, Aleppo, Syria.
113. Olimov, U. and Y. Fayzullaev. 2011. Assessing development strategies to achieve the MDGs in the Republic of Uzbekistan. United Nations Department for Social and Economic Affairs. 1-55.
114. Raupova O., H. Kamahara, N. Goto. 2014. Assessment of physical economy through economy-wide material flow analysis in developing Uzbekistan. Journal of Resources, Conservation & Recycling. Elsevier. RECYCL 2865.
115. RSN, Responsible Sourcing Network. 2012. From the field: Travels of Uzbek cotton through the value chain. San Francisco, USA.
116. Rywkan, M., 2005. Stability in Central Asia: engaging Kazakhstan, A report on US interests in Central Asia and US-Kazakhstan relations. National Committee on American Foreign Policy, New York. Available at www.ncafp.org.
117. Schandl, H. and J. West. 2010. Resource use and resource efficiency in the Asia-Pacific region. Global environmental change. 20: 636-647.
118. SCS, the State Committee of the Republic of Statistics. 2012. Uzbekistan Statistical Yearbook, Tashkent, Uzbekistan.
119. Shadmanov, E. 2010. Issues of balanced development in Uzbekistan economy. International Cross-Industry Journal. 5 (2): 43-44.
120. Stark, M and J. Ahrens. 2012. Economic reform and institutional change in Central Asia: towards a new model of the developmental state? PFH Göttingen und European Business School.
121. The governmental portal of the Republic of Uzbekistan. www.gov.uz
122. The online portal for material flow data www.materialflows.net/home/.
123. UN ESCAP, United Nations Economic and Social Commission for Asia and the Pacific. 2010. Preview Green Growth, Resources and Resilience. Environmental sustainability in Asia and the Pacific. Bangkok, Thailand.
124. UNDP, SCNP, United Nations Development Program and State Committee for Nature Protection of Uzbekistan. 2008. Environmental profile of Uzbekistan based on indicators. Tashkent, Uzbekistan.
125. UNDP, United Nations Development Program. 2010. Livestock production in Uzbekistan: current state, challenges and prospects. Tashkent, Uzbekistan.
126. UNEP, United Nations Development Program. 2011. Decoupling natural resource use and environmental impacts from economic growth. Switzerland.
127. UNEP, United Nations Development Program. 2012. Global Outlook on SCP Policies: taking action together.
128. USGS, United States Geological Survey. 2011. Minerals Information. http://minerals.usgs.gov/minerals/
129. UZINFORINVEST.2012.Invest in Uzbekistan. Available at www.uzinfoinvest.uz
130. Vildanova, G. 2006. Forest and forest products. Country profile Uzbekistan. New York, Geneva.
131. Wegner, A.L. 2002. Materials in the Economy—Material Flows, Scarcity, and the Environment. U.S. Geological Survey Circular 1221.
132. Weisz, H., F. Krausmann, C. Amann, N. Eisenmenger, K.-H. Erb, K. Hubacek, and M. Fischer-Kowalski. 2005b. The physical economy of the European Union: Cross-country comparison and determinants of material consumption. Ecological Economics 58(4): 676–698.
133. West, J and H. Schandl. 2013. Material use and material efficiency in Latin America and the Caribbean. Ecological Economy. 94: 19-27.
134. WB, World Bank, 2012. World Development Indicators 2012. World Bank.
135. Xu, M. and T. Zhang. 2007. Material flows and economic growth in developing China. Journal of Industrial Ecology. 11 (1):121-1-40.
136. Yuldashbaev, N. 2014. Uzbekistan Fresh Deciduous and Stone Fruits. USDA. Tashkent. Uzbekistan.

# Chapter V

# Assessment of Energy transition through "MFA-based energy indicators set" in a transition economy - Uzbekistan

# 5.1 Introduction

Increase in energy demand particular in developing economies (*BP Statistical Review, 2013*) has defined long-term targets and implement strategies to balance their energy needs: providing security of supply, remaining competitive, environmentally sustainable and socially acceptable (*Soyhan, 2008; Warr et al., 2010; Hu et al., 2014*). A better understanding of the patterns and trends of changes in energy flow helps to understand the dynamics of society and environment relations.

In this study we assess the energy transition in Uzbekistan during socioeconomic development by applying material flow analysis. Uzbekistan`s economy energy sector has played a significant role that accounts for 7 % of GDP and 72 % of the government's investment program and, in terms of physical trade balance, almost 70% of total commodity exports (*SCS, 2012*). Uzbekistan's economy driven by mainly energy resources particularly natural gas. Primary energy demand in Uzbekistan is forecasted to increase with a projected average growth rate of 1.7% by 2025 (*OG Analysis, 2013*). Consequently, integrated modern resource management analysis, exploring potential new reforms and policy implementations for sustainable energy development are necessary for sustainable socio-economic development. Other central Asian countries, Kazakhstan and Turkmenistan also are improving their economic growth due to their rich supply of natural resources. However, focus on exploitation of natural resources for economic development can lead to climate change issues in these countries.

In our previous paper (*Raupova et al., 2014*) we evaluated macroscopic economic activities through applying Economy-wide MFA and aggregated indicators. We found that energy had important role as main commodity in economic, social and environmental aspects. Additionally obtained results show that indicators that are too aggregated may conceal various environmental impacts of different material flows.

Based on previous results we focus on disaggregated exploration of energy flows in Uzbekistan by considering economic, social, political and environmental factors of sustainable energy development through developed energy flow indicators set.

This study focuses on the assessment of energy trends and development of an energy flow indicators set through the methodology of material flow analysis in order to monitor the potential for sustainable energy development in Uzbekistan.

An energy transition is defined here as a fundamental structural change in the energy sector by accounting of all energy carries of a country, like the share of renewable energies, the promotion of energy efficiency and energy policy development.

# 5.2 MFA-based energy flow indicator

In this research we accounted energy sources for the assessment of energy transition in Uzbekistan by employing the following MFA-based indicators: Domestic Energy Extraction (DEE) covers the total primary energy extraction in Uzbekistan which enters the economic system for further processing or direct consumption. As the primary energy sources, we compiled data of natural gas, crude oil, coal and hydro power. Energy Import (IMPe) comprises of both the primary and secondary energy sources imported. The secondary energy sources include oil by-products (gasoline, kerosene, diesel and so on), liquefied natural gas and electricity. Energy Export (EXPe) includes also both primary and secondary energy.

Domestic Energy Input (DEI) is a derived indicator calculated from the sum of DEE plus IMPe (Equation 9).

$$DEI=DEE+IMP_e \qquad \text{(Eq.9)}$$

$$DEC=DEI+EXP_e \qquad \text{(Eq.10)}$$

Domestic Energy Consumption (DEC) measures the total quantity of energy used within an economic system. The DEC is calculated by subtracting EXPe from DEI (Equation 10).

In this study we calculated hidden energy flows for primary energy sources. Hidden energy flows (HFe) are classified as quantity of energy requires during extracting of primary energy sources that can modify or damage the environment even though they have no economic value. There are two concepts associated with HFe: Unused Domestic Energy Extraction (UDEE) and Indirect Energy flows associated to Imports and Exports (IFIe and IFEe). UDEE comprises the energy of overburden or parting energy from mining during domestic energy extraction process. Indirect energy flows, however, indicates energy that has been required for manufacturing (upstream energy requirements) and comprises both DEE and UDEE. An upstream energy requirement expresses the amounts of used primary extracted energy required along the whole production chain of an imported and exported energy (*Hinterberger et al., 2003*) (Equation 11).

$$HF_e = UDEE + IFI_e + IFE_e \qquad \text{(Eq.11)}$$

In our study applied ratios for calculation of UDEE and IFIe showed in Table 11. UDEE column of Table 11 shows domestic hidden energy flows which explains the amount of the energy were used for extracting energy marketed (used) in country. Which means to produce of 1 ton natural gas marketed (used), country used 0.17 tons non-marketed (unused) energy annually. Specific ratios for hidden flows to used (marketed) extractions of natural gas and crude oil were taken as 0.17 and 0.08 tons per net extraction from the database of the Wuppertal Institute (*Bringezu et al., 2001*). We assumed the same technology base in Uzbekistan with EU-15 only for this study. The hidden flow ratio for hard coal was estimated on a global level (covering 91 % of global mining) at 3.98 tonnes per tonne saleable coal.

**Table 11. Ratio for calculation of hidden energy flows**

| Energy | UDEE (tons/ton net extraction) | IFIe (tons/ton imported) |
|---|---|---|
| Natural Gas | 0.17 (EU-15) | 0.56 (Russia&former Soviet Union) |
| Crude Oil | 0.08 (EU-15) | 0.17 (EU-15) |
| Coal | 3.98 (Global level) | 5.13 (Russia&former Soviet Union) |

IFIe column of Table 11 indicates foreign hidden energy flows which explains how much energy used in international territory for energy imported. In our study we calculated IFIe only for primary energy sources by using ratio which is taken from the database of Wuppertal Institute in Germany for Russia and EU-15 case. Since the main basement of energy industry in Central Asia was built by the time period of incorporated with Soviet Union, we assumed that the same ratio of IFIe for natural gas 0.56 and coal 5.13 ton per ton imported in Uzbekistan can be applied. For IFIe ratio of crude oil we used 0.17 ton per ton imported crude oil.

It has to be noted, that other ratios which are particular taken from western European countries can only provide estimations as the ratios differ markedly between countries, years, or alternative methods of extraction. Due to lack of data, the calculation indirect energy flows associated to import of energy by-products is not included in this research. We consider this issue as next step of our investigation.

As for "Material" flow analysis, "Hidden Material Flows" are often used. The difference between HFe and Hidden Material Flows is as follow: HFe accounts the only upstream energy that was required during the extraction and production process chain of energy (consumed or traded) but has no economic value in country. HFe can be applied only for energy carries during extraction and production chain. Hidden Material Flows account the upstream materials that were required during the extraction and manufacturing process chain of material (consumed or traded) but has no economic value in country. An upstream material requirement expresses the amounts of used primary extracted material that required along the whole production chain.

Calculation of Hidden Material Flows comes from based on individual material flow accounts. It focuses on selected raw materials or semi-finished products at various levels of detail and application (cement, paper, iron and steel, copper, plastics, timber (*OECD, 2008*).

Total Energy Requirement (TER) measures the total amount of energy, whether for use in production and consumption activities or not, and whatever their origin is (domestic, rest of the world). In economy-wide energy flow accounting TER equals DEI plus hidden energy flows of UDEE and IFIe (Equation 12). TER is an overall indicator developed to describe not only the amount of direct flows of energy sources used by the economy, but also the indirect energy flows which are involved in such production. By assessing the hidden energy flows we can detect the potential of energy efficiency level and environmental monitoring.

$$TER = DEI + UDEE + IFI_e \qquad \text{(Eq. 12)}$$

As for "Material" Flow Analysis, there is an important factor named as Total Material Requirement (TMR). The difference between TER and TMR is same as that between HFe and Hidden Material Flows.

Total Energy Consumption (TEC) is TER minus EXPe and IFEe (Equation 13). In Figure 35, the diagram of energy flow from extraction until final use by sectors is presented by using MFA-based indicators for year of 2012.

$$TEC = TER - EXP - IFE_e \qquad \text{(Eq. 12)}$$

During our calculation are all data are obtained from IEA for the period 1991-201226) excluding of the data of secondary energy sources which were requested from the State Committee of the Republic of Uzbekistan on Statistic for selected time of period. In our calculations, all MFA-based energy flow indicators are considered in units of million tonnes of oil equivalent (Mtoe).

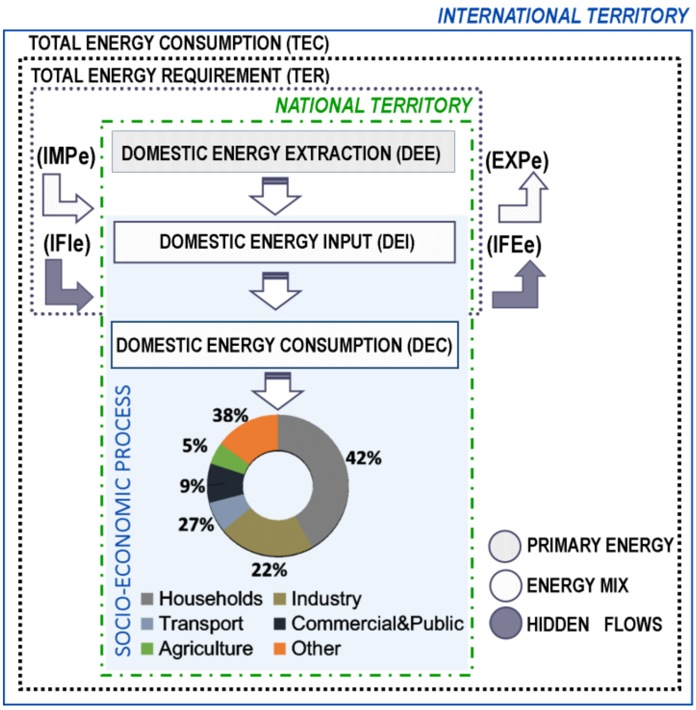



**Figure 35. Energy flow chart with MFA-based indicators in Uzbekistan. 2012.**

# 5.3 Energy extraction in Uzbekistan

Uzbekistan has four significant primary energy sources. They are natural gas, oil, coal and hydro. Sizeable fossil fuel reserves and natural gas account for 70 % in terms of energy content. Fossil fuels are currently the primary source for electricity generation, heating and other uses in Uzbekistan. In terms of gas production, the country ranks sixteenth in the world and third in Eurasia. DEE is depicted in Figure 36 by dividing primary energy sources in 1991-2012. Since 1991, the total DEE pattern in Uzbekistan changed dramatically and increased by 43% from 39.6 in 1991 to 56.7 Mtoe in 2012 with an AGR of 1.7%. But if we compare the energy sources of natural gas, oil and hydro all of them increased by 51%, 17% and 85% respectively, while coal decreased to 43% during the period of study. The proportion of fossil fuels dominates with 99% in total DEE while renewable energy represents only 1% during these two decades. In Uzbekistan, 85% of the extracted fossil fuel energy comes from natural gas while 12% comes from oil, 2% from coal and hydro 1% respectively. The primary energy mix varied significantly during the decade, with the share of natural gas increasing robustly.

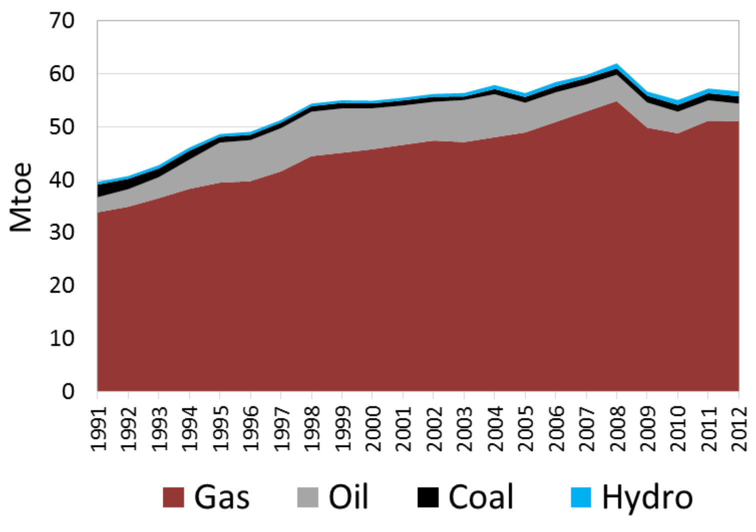



**Figure 36. Domestic Energy Extraction in Uzbekistan (1991-2012), Million tonnes of oil equivalent**

## 5.4 Energy Input in Uzbekistan's socioeconomic process

DEI is defined as the flow of energy that enters into an industrial economy (Equation 9). During the period of study, the trend of DEI in Uzbekistan had increased insignificantly from 53.6 Mtoe to 57.8 Mtoe (Figure 37). Since DEI in sum of the DEE ad IMPe indicators, this could be explained by two factors: a) lower annual growth rate of DEE of 1.7% due to insufficient infrastructure and investment development in the energy sector, limited oil pipeline and network storage infrastructure and inadequate national reforms on the diversification of the energy supply mix (*IBRD/WB, 2013*), b) a reduction in energy import dependency due to adoption of energy self-sufficiency policy implementation in Uzbekistan. In 1991-1995, the proportion of DEE and IMPe was 80% to 20%. Since 1995 the share of IMPe has contracted and DEE appeared as the dominant indicator accounting for 96% of DEI during the second decade (Table 12). DEI consisting of IMPe decreased significantly, which was mainly driven by oil products during the period of study. The AGR of DEI in the first decade was faster, 0.7%, than the growth rate of the second decade which was -0.1%. This could be explained by the first factor "a)". However, despite a sharp economic recession for a short period, Uzbekistan achieved energy self-sufficiency from 1995. It highlights the extent to which Uzbekistan has no need to rely on imports in order to meet its energy needs which is a prerequisite for the country's long-term sustainable development.

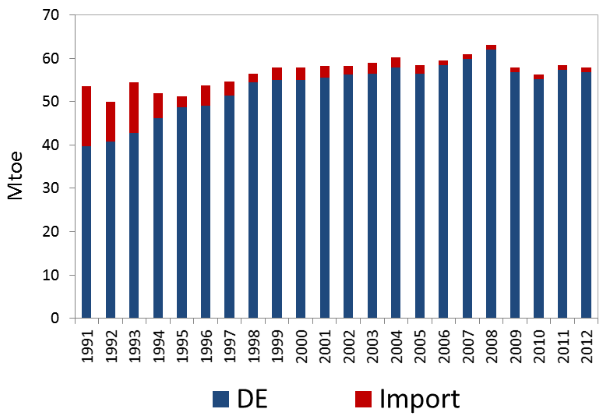



**Figure 37. Domestic Energy Input in Uzbekistan (1991-2012), Mtoe**

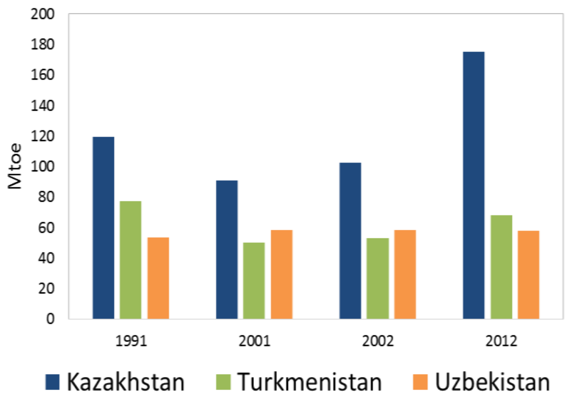



**Figure 38. International comparison of Domestic Energy Input (1992-2011), Mtoe**

Comparative analysis showed that the DEI in Kazakhstan possessed the highest values and increased from 119.8 to 175.3 Mtoe, which was driven by an increase in gas and oil production, while the DEI of Uzbekistan had the lowest values among comparative countries during the two decades of study (Figure 38). In all economies, dependence on the import of energy products significantly decreased during the period of study, which provides a sound starting point for the pursuit of sustainable energy development.

### Table 12. MFA-based Energy flow indicators set for Kazakhstan, Turkmenistan and Uzbekistan, (tonnes per capita)

| MFA-based indicators | Kazakhstan | | | | Turkmenistan | | | | Uzbekistan | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *unit* | *Indicator share,%* | | | *unit* | *Indicator share,%* | | | *unit* | *Indicator share,%* | | |
| **DEI=DEE+IMPe** | *t/cap* | *DEI* | *DEE* | *IMPe* | *t/cap* | *DEI* | *DEE* | *IMPe* | *t/cap* | *DEI* | *DEE* | *IMPe* |
| 1991 | *7.2* | *100%* | *77%* | *23%* | *20.3* | *100%* | *96%* | *4%* | *2.6* | *100%* | *74%* | *26%* |
| 2001 | *6.2* | *100%* | *92%* | *8%* | *10.9* | *100%* | *100%* | *0%* | *2.3* | *100%* | *95%* | *5%* |
| 2012 | *10.4* | *100%* | *94%* | *6%* | *13.1* | *100%* | *100%* | *0%* | *1.9* | *100%* | *98%* | *2%* |
| **DEC=DEI-EXPe** | *t/cap* | *DEC* | *DEI* | *EXPe* | *t/cap* | *DEC* | *DEI* | *EXPe* | *t/cap* | *DEC* | *DEI* | *EXPe* |
| 1991 | *4.1* | *56%* | *100%* | *44%* | *8.9* | *44%* | *100%* | *56%* | *2.3* | *91%* | *100%* | *9%* |
| 2001 | *2.4* | *39%* | *100%* | *61%* | *3.3* | *31%* | *100%* | *69%* | *2.0* | *88%* | *100%* | *12%* |
| 2012 | *4.4* | *42%* | *100%* | *58%* | *5.0* | *38%* | *100%* | *62%* | *1.6* | *83%* | *100%* | *17%* |
| **TER=DEI+(UDEE+IFIe)** | *t/cap* | *TER* | *DEI* | *UDEE+IFIe* | *t/cap* | *TER* | *DEI* | *UDEE+IFIe* | *t/cap* | *TER* | *DEI* | *UDEE+IFIe* |
| 1991 | *24.0* | *100%* | *30%* | *70%* | *24.2* | *100%* | *84%* | *16%* | *4.0* | *100%* | *64%* | *36%* |
| 2001 | *16.5* | *100%* | *38%* | *62%* | *12.6* | *100%* | *87%* | *13%* | *3.0* | *100%* | *77%* | *23%* |
| 2012 | *24.1* | *100%* | *43%* | *57%* | *15.1* | *100%* | *87%* | *13%* | *2.5* | *100%* | *76%* | *24%* |
| **TEC=TER-(EXPe+IFEe)** | *t/cap* | *TEC* | *TER* | *EXPe+IFEe* | *t/cap* | *TEC* | *TER* | *EXPe+IFEe* | *t/cap* | *TEC* | *TER* | *EXPe+IFEe* |
| 1991 | *11.2* | *47%* | *100%* | *53%* | *7.1* | *29%* | *100%* | *71%* | *3.5* | *88%* | *100%* | *12%* |
| 2001 | *5.8* | *35%* | *100%* | *65%* | *1.2* | *10%* | *100%* | *90%* | *2.5* | *84%* | *100%* | *16%* |
| 2012 | *11.4* | *47%* | *100%* | *53%* | *3.0* | *20%* | *100%* | *80%* | *2.0* | *79%* | *100%* | *21%* |
| *Here DEI = 100% is considered to show the ratio of foreign market dependency and national production of energy in country* | | | | | | | | | | | | |
| *Here TER = 100% is considered to show the ratio of hidden energy flows including domestic unused and indirect flows to imports and exports* | | | | | | | | | | | | |

# 5.5 Total Energy Requirement in Uzbekistan

Figure 39 presents TER and DEI during the period of study. The difference between these two indicators is the result of HFe. The share of HFe in the TER of Uzbekistan reduced from 36% in 1991 to 24% in 2012 while DEI increased from 64% to 73% in the same period (Table 12). This could be explained by the reduction in energy imports and production of coal products which possesses a higher ratio calculation of the hidden energy flows in Uzbekistan.

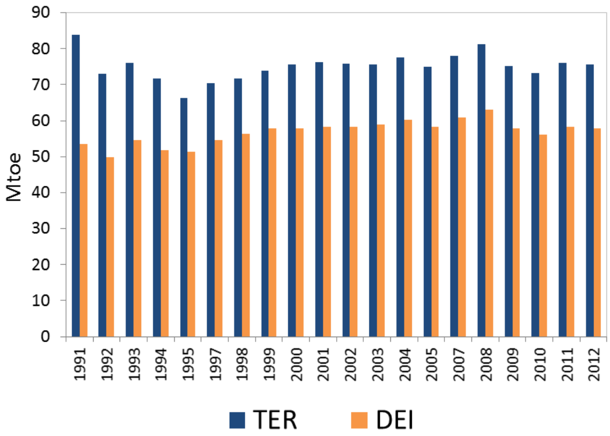



**Figure 39. Relationship between TER and DEI in Uzbekistan (1991-2012), Mtoe**

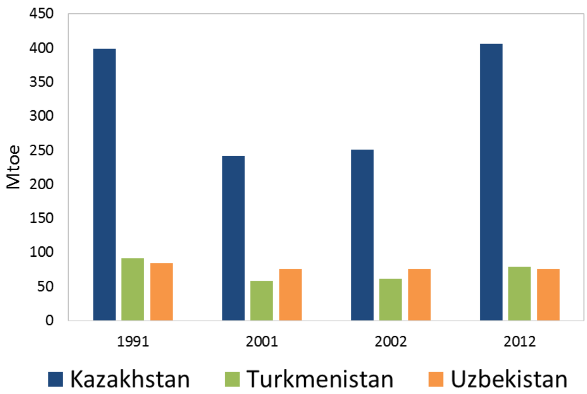



**Figure 40. International comparison of Total Energy Requirement (1992-2011), Mtoe**

Comparative analysis shows that the TER of Uzbekistan was the lowest while Kazakhstan possessed the highest TER at 348.8 Mtoe, which associated with the highest share of hidden energy flows at 60%, which was an average share during the period of study (Figure 40).

# 5.6 Consumed Energy in Uzbekistan

DEC is measured to estimate the quantity of energy consumed by a national economy. An assessment of DEC is crucial since Uzbekistan has pursued a high-intensity energy development model that may bring geological, spatial limits and the occurrence of heavy environmental impacts. Obtained results showed that DEC in Uzbekistan grew from 48.3 in 1991 to a high point of 53.2 Mtoe in 2002 then declining to 48.3 Mtoe in 2012 (Figure 41). Natural gas dominates in the energy supply mix during the period of study. Specifically, it accounts for 81% of the total primary energy supply while oil, coal and electricity contribute 14%, 3% and 1%, respectively. According to the equation (10), the share of energy exports was 9% in 1991 and nearly doubled to 17% in 2012 (Table 12). In energy exports, natural gas was the primary commodity accounting for an average of 72% in the 1991-2012 period. Among comparative economies, with regard to total DEC, Uzbekistan required only 10% of its energy source from the international energy market while Kazakhstan and Turkmenistan required an average of 50% and 60% energy across the two decades respectively. It is apparent that a higher dependency on the international market in Kazakhstan and Turkmenistan reduces economic security, whilst Uzbekistan has significantly lower dependence on the international market, reducing its exposure to such risk.

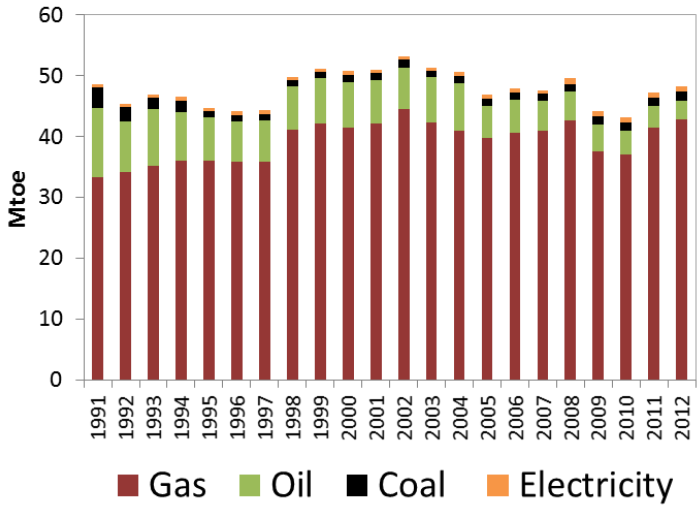



**Figure 41. Domestic Energy Consumption in Uzbekistan (1991-2012), Mtoe**

Uzbekistan ranks highly as a country using elevated levels of energy intensity across all links of the value chain. The main sources of energy inefficiencies are gas flaring, the low efficiency of thermal power plants (with only 34% efficiency), trans-mission and distribution losses (20% of net generation) and low energy efficiency on the demand side. Improvement of energy efficiency of thermal power plants in Uzbekistan is important due to following reasons:

- Thermal Power Plants represent 86% of the total power generation capacity in Uzbekistan18);

- Most power generation assets are 40–50 years old, in poor condition, and require replacement and rehabilitation. Since 1991, only two power capacity expansion projects have been completed: (i) rehabilitation of two 300 MW steam cycle units at Syrdarya TPP, and (ii) construction of an 800 MW steam cycle unit at Talimarjan TPP (*Allayev, 2007*).

DEC results depict that the residential and industry sectors are the largest consumers, accounting for 42% and 22% of the total consumption in 2012 respectively (Figure 35) (IEA, 2012). The residential sector utilizes gas primarily for cooking, water and space heating. Electricity generation accounts for the largest share of industrial consumption. In 2010, gas-based electricity generation accounted for 82% of total generation (*EIA, 2013*).

In Figure 42 EI is defined as DEC divided by GDP. Between 1991 and 2012, Uzbekistan EI decreased by a factor of three with an AGR of -6.0%. During its transition period, Uzbekistan's policy makers made great strides in reducing energy consumption, promoting energy conservation, improving energy efficiency, and reducing the economic, environmental, and social costs of its energy sectors. However, despite this, Uzbekistan is still one of the most energy intensive countries in the world. It has significantly higher consumption levels compared to Kazakhstan and Turkmenistan during the period of study. Additionally, CO2 emissions per capita have decreased in Uzbekistan and are the lowest across comparative countries (Figure 42). This could be explained by the reduction of coal production in the energy supply mix and the consumption of natural gas as the dominant energy source in Uzbekistan during the period of study.

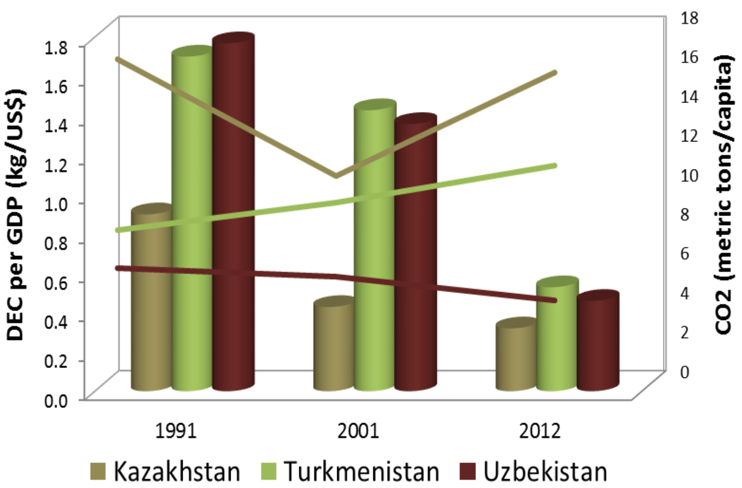



**Figure 42. Energy Intensity, CO2 emissions in Kazakhstan, Turkmenistan and Uzbekistan (1991-2012)**

## 5.7 Comparative analysis of total energy consumption

International comparison analysis shows that, Kazakhstan presented as the highest TEC of 11.4 tons per capita (t/cap) while Turkmenistan and Uzbekistan had 3.0 and 2.0 t/cap respectively in 2012 (Figure 43). In TER for Kazakhstan, hidden energy flows accounted for 60% which mostly come from coal production during two decades. Despite low value of TEC/cap, Turkmenistan shows the highest export intensive country with share of the sum of EXPe and IFEe an average of 80% (Table 12). Trend of TEC in Uzbekistan depicted the lowest values and reduced during two decade due to: 1) inadequate diversification of energy system; 2) lower ratio in the calculation of hidden energy flows; 3) highest population growth among comparative economies

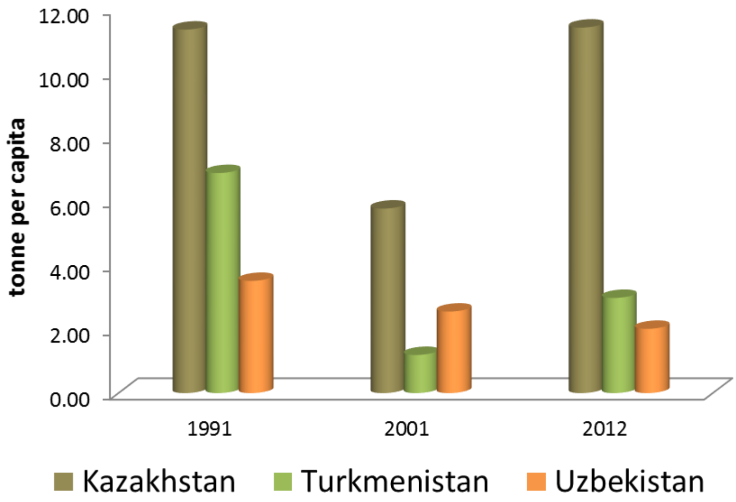



**Figure 43. Total Energy Consumption in Kazakhstan, Turkmenistan, and Uzbekistan (1991-2012), tonne per capita**

# 5.8 Opportunities for renewable energy and energy policy implementation

In this chapter we discussed energy policy implementation in Uzbekistan to present a connection between energy transition changes and national policy implementation of country during two decades. We found through our results analyzed in chapter 3 and policy discussion in chapter 4 that up today Uzbekistan's energy policy implementations mainly focused on economic and social development in country.

However, we discovered through MFA-based energy indicators set that dependency on fossil fuels and dominated domestic hidden energy flows have alarmed environmental issues in Uzbekistan including in comparative countries of our study. Except future plan on construction of solar plant, there is no government or private sector energy policy or activity in Uzbekistan on sustainable energy development and mitigating environmental problems through adopting integrated system approach by considering supply and demand sides of energy.

Uzbekistan possesses enormous potential with energy sources including solar, biomass and biogas, while the potential of smaller-scale hydroelectric and wind power is also significantly high (*Eshchanov, 2011*) (Table 13). The government has indicated its commitment to increase the share of renewable energy in the generation mix. Specifically, it is planning to construct 400 MW of small hydro power plants, a 100 MW solar PV plant and a 100 MW wind farm. Up today in total 40 thousand square meters solar panels were installed in Uzbekistan. However, the penetration of solar energy technologies is limited to several off-grid installations, primarily they include solar heaters used by industrial enterprises and households in rural areas (*TTA, 2007*).

It is apparent that Uzbekistan has a significant opportunity to develop its potential and as such needs to ensure that government and private sector energy policy and activity are aligned to maximize the benefits of the available resources in a sustainable and forward thinking manner.

Since gaining independence, Uzbekistan has adopted several national programs and policy implementations with regard to energy security and sustainable future energy development. In 1991-1996, the government of Uzbekistan adopted a national program on energy independency and a reorientation of the fuel-energy market to achieve priority social goals. Since 1995, Uzbekistan gained its energy self-sufficiency and established a ten year policy program focusing on the development and reconstruction of power generation systems for improving energy efficiency during 2001-2010 years. As the country focuses on a more market-oriented economy, Uzbekistan adopted a program introducing market management mechanisms and incentives for domestic and foreign investment into the energy sector between 1997-2002 periods. In the second decade of independence, much more effort was put into the development of renewable energy resources in Uzbekistan. In 2009 Uzbekistan signed The International Renewable Energy Agency IRENA Statute; establishment of International Solar Institute (2012) which could be for a source for future investigation into solar energy development in Uzbekistan. Additionally, some decrees and laws demonstrate serious intent by the government of Uzbekistan.

**Table 13. Uzbekistan's renewable energy sources potential**

| Potential | Total in Mtoe | including types of energy, Mtoe | | | | |
|---|---|---|---|---|---|---|
| | | Solar | Hydro | Biomass | Wind | Geothermal |
| Gross | 50986.9 | 50973.0 | 9.2 | 2.3 | 2.2 | 0.2 |
| Technical | 179.3 | 176.8 | 1.8 | 0.3 | 0.4 | - |
| Utilized | 0.6 | - | 0.6 | - | - | - |

Source: Eshchanov B.R et al. 2011[31)]

# 5.9 Conclusions

This initial assessment of energy transition, by using MFA has been conducted for Uzbekistan with a comparison of Kazakhstan and Turkmenistan. Energy flow indicator sets were developed for these countries' energy transition for the 1991-2012 periods. From the results we found that:

- DEE of primary energy has increased by a factor of 1.4 but with a small change in proportion of energy mix in two decades.
- DEI in Uzbekistan insignificantly changed with annual growth rate of 0.4% in period of study.
- International comparison of DEI per capita is depicted that the share of IMPe dramatically contracted from 1/5 to 1/15 for Kazakhstan, from 1/25 to 0/0 for Turkmenistan and from 1/4 to 1/45 for Uzbekistan in period of study. It shows in all economies have no dependency for energy import in order to meet their energy needs.
- In 2012 DEC per capita in Uzbekistan was the smallest value of 1.6 t/cap in comparison while in Kazakhstan 4.4 and in Turkmenistan 5.0 t/cap respectively.
- In TER HFe accounts 60% in Kazakhstan, 14% in Turkmenistan and 27% in Uzbekistan an average which mainly came from domestic hidden energy flows. This indicates that in all countries high risks to the land erosion, air pollution and climate change which can be threaten to environmental and social aspects.
- Energy intensity DEC per GDP for Uzbekistan and Turkmenistan has almost contracted same from 1.7 to 0.5 kg/US$ while for Kazakhstan from 0.9 to 0.3 kg/US$ in 1991-2012.

Overall through obtained results we summarized that management of energy sources takes a major role in two important tasks in Uzbekistan: 1) achieving society's priority objectives by extensive access to energy in households as Uzbekistan is the most populated country among comparative countries; 2) development of the economic performance of the country by increasing the export of energy products during the period of study. However, it should be noted Uzbekistan is still highly dependent on fossil fuel products which can cause serious environmental issues from a long term perspective.

The high energy intensity of the country has to be addressed through development mechanisms focusing on energy conservation and energy efficiency in high energy demand sectors. For the development of this mechanism, we suggest employing MFA methodology that will enable a deeper assessment of energy flows and system boundaries that, consequently, will promote improved energy efficient performance of the system.

# 5.10 Reference


137. BP Statistical Review of World Energy. 2013. London. UK.
138. Soyhan, H. S. 2008. Sustainable energy production and consumption in Turkey: A Review. Renewable and Sustainable Energy Reviews. 13: 1350-1360.
139. Warr, B., R. Ayres, N. Eisenmenger, F. Krausmann, H. Schandl. 2010. Energy use and economic development: A comparative analysis of useful work supply in Austria, Japan, the United Kingdom and the US during 100 years of economic growth. Ecological Economics. 69: 1904-1917.
140. Hu, H., X. H. Zhang, L. Lin. 2014. The interactions between China's economic growth, energy production and consumption and the related air emissions during 2000–2011. Ecological Indicators. 46: 38-51.
141. OECD, the Organization for Economic Cooperation and Development. 2008. Measuring Material Flows and Resource Productivity. Volume I. The OECD Guide OECD, Paris.
142. Raupova, O., H. Kamahara, N. Goto. 2014. Assessment of physical economy through economy-wide material flow analysis in developing Uzbekistan. Resources, Conservation & Recycling. 89: 76-85.
143. CIA, Central Intelligence Agency. 2013. The World Factbook. Washington, D.C. USA.
144. SCS, the State Committee of the Republic of Uzbekistan on Statistics. 2012. Uzbekistan Statistical Yearbook, Tashkent, Uzbekistan.
145. OG Analysis. 2013. Uzbekistan Oil and Gas Strategic Analysis and Outlook to 2025. www.oganalysis.com Germany.
146. Hinterberger, F., S. Giljum, M. Hammer. 2003. Material Flow Accounting and Analysis. SERI. Vienna. Austria.
147. Bringezu, S. and H. Schütz. 2001. Total Material Requirement of the European Union. Technical Part. Technical Report No 56. Copenhagen.
148. IEA, International Energy Agency. 2013. Energy balances statistics. Energy flow charts.
149. Shadmanov, E. 2010. Issues of balanced development in Uzbekistan economy. International Cross-Industry Journal. 5 (2): 43-44.
150. International Bank for Reconstruction and Development/World Bank. IBRD/WB. 2013. Uzbekistan Energy/Power Sector Issues Note. Washington DC. USA.
151. Allayev, K. R. 2007. Energy in Uzbekistan. Tashkent. Uzbekistan.
152. EIA, Energy Information Administration. 2013. Uzbekistan energy overview. United States.
153. Eshchanov, B. 2011. Potential of renewable energy sources in Uzbekistan. Journal of knowledge management and economics and information technology. 7:1-17
154. Technology Transfer Agency. 2007. Renewable energy development in Uzbekistan. Washington D.C.

# Chapter VI

# CONCLUSIONS

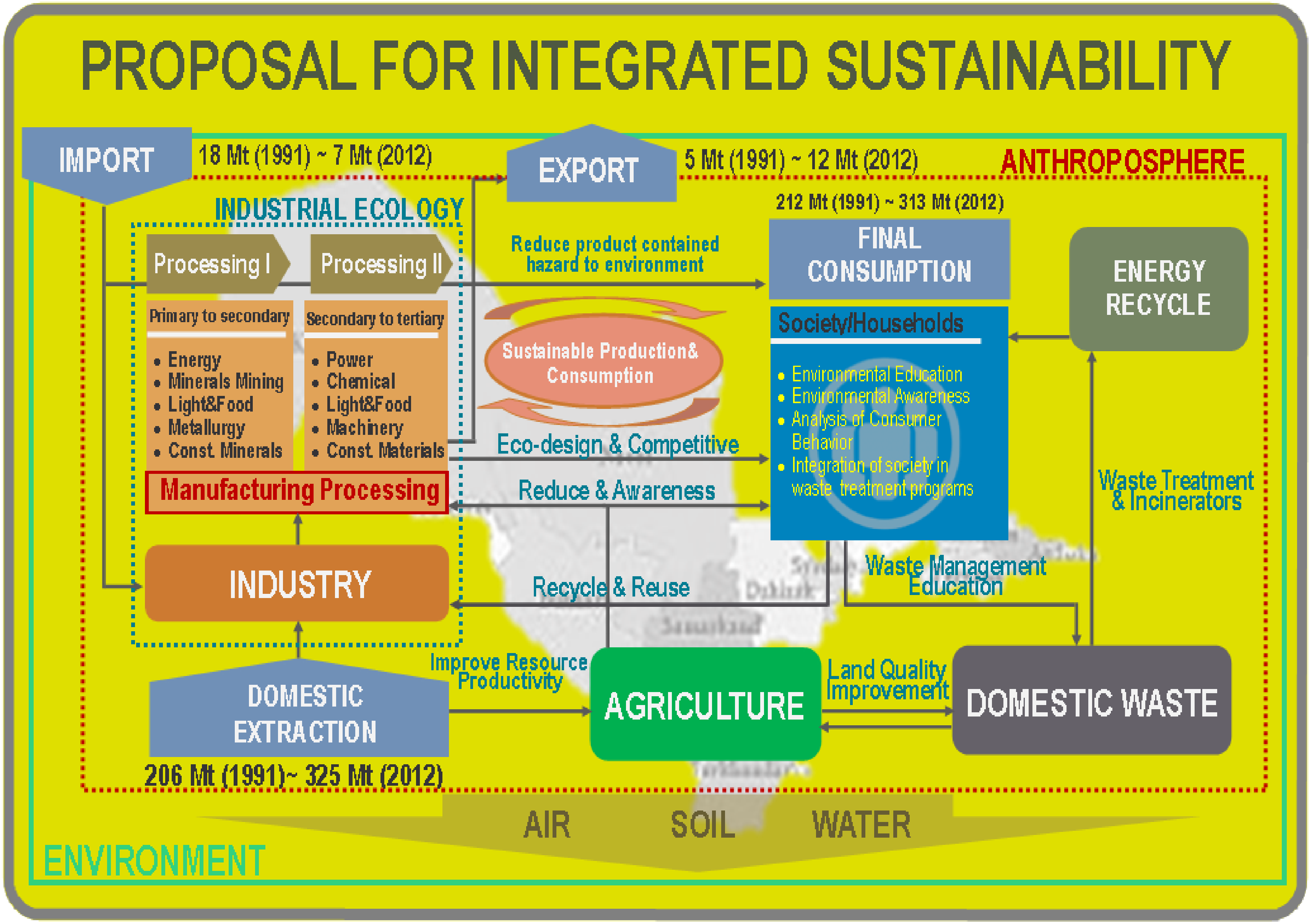
# CONCLUSIONS

Uniquely, indeed for the first time, the assessment of the physical economy in 1991-2012 for the long–term perspective for Uzbekistan was discussed and analyzed using economy-wide material flow analysis (EW-MFA) method. We presented the pattern of variations, trends, absolute amounts, components and efficiencies of the physical material indicators of Uzbekistan's economy. In regards to the questions raised in the research objectives section the following conclusions are drawn from the whole analysis of our three divided chapters:

- EW-MFA input indicators of direct material input and total material requirement continuously increased in Uzbekistan with an average growth rate of 2.8% and 2.3% during the period of study. In direct material input, domestic extraction indicators was a dominant with share of 95% average. In total material requirement, the share of domestic and foreign hidden flows was 30% average over the period of study. We defined close link between EW-MFA indicators and policy implementation which can give supportive suggestion for further researches and policy makers;
- The main driven forces behind economic growth in Uzbekistan were increase in domestic production of materials, import substitution and expanding export of commodities mainly fossil fuel products;
- Relative decoupling has occurred: GDP growth shows faster than growth of domestic material consumption during second decade of study. Affluence and technology were broadly comparable to increasing population as a driver of DMC growth in comparative analysis. For Uzbekistan case, we found that it is not enough to improve technological factors to gain material efficiency. Economic growth and an increase in population may have a rebound effect;
- In international comparative analysis domestic extraction indicator showed lower than central Asia countries while it presented higher than industrialized economies. Domestic material consumption per capita depicted the same line with world average but lower than other comparative countries;

The research summarizes that the development within all categories of material flows was indispensable for the socio-economic development of Uzbekistan in the transition period. The management of all material flows plays a major role in two important tasks: firstly, achieving society's main objectives by extensive access to grain and energy products, and secondly the development of economic performance of the country by increasing industrial base and export commodities. However, the economic development and increase of industrial base caused the growth in resource consumption accompanied with waste and pollution to the environment in Uzbekistan. Based on our observations and findings, we suggested to employ integrated system for sustainable production and consumption (A.1) in Uzbekistan. We also believe that the emphasis should be given to sustainable and effective management of resources in the medium and long term prospective.

**Appendix .1** Proposal for Integrated Sustainability in Uzbekistan



**Appendix .2** Data Summary

Domestic Extraction (DE), Million tonnes (Mt)

| DE (Mt) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fossil Fuels** | 46 | 47 | 48 | 52 | 54 | 54 | 57 | 60 | 61 | 61 | 62 | 64 | 61 | 64 | 63 | 65 | 67 | 70 | 68 | 67 | 64 | 63 |
| Natural Gas | 38 | 39 | 41 | 42 | 44 | 44 | 46 | 49 | 50 | 51 | 52 | 54 | 52 | 54 | 54 | 57 | 59 | 61 | 60 | 59 | 57 | 55 |
| Crude Oil | 3 | 3 | 4 | 6 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 5 | 5 | 5 | 4 | 4 | 4 | 3 |
| Coal | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 |
| **Biomass** | 37 | 37 | 37 | 38 | 39 | 36 | 36 | 37 | 38 | 38 | 41 | 43 | 44 | 48 | 51 | 55 | 58 | 62 | 66 | 71 | 76 | 79 |
| Primary crops | 12 | 12 | 11 | 11 | 12 | 11 | 12 | 12 | 12 | 12 | 13 | 14 | 15 | 15 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Crop residues used | 7 | 7 | 7 | 7 | 8 | 7 | 8 | 8 | 8 | 7 | 8 | 9 | 10 | 10 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Grazed biomass | 18 | 18 | 19 | 20 | 19 | 18 | 17 | 17 | 18 | 19 | 21 | 19 | 20 | 22 | 23 | 26 | 29 | 32 | 34 | 37 | 42 | 44 |
| Wood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Construction Minerals (CM)** | 67 | 98 | 92 | 64 | 52 | 48 | 82 | 61 | 77 | 60 | 85 | 77 | 54 | 68 | 64 | 74 | 84 | 99 | 89 | 105 | 124 | 120 |
| Cement-related CM | 64 | 95 | 89 | 61 | 49 | 45 | 56 | 36 | 37 | 33 | 38 | 44 | 37 | 46 | 46 | 53 | 65 | 68 | 68 | 64 | 65 | 61 |
| Asphalt- related CM | 3 | 3 | 3 | 3 | 3 | 3 | 11 | 3 | 6 | 3 | 10 | 5 | 3 | 3 | 2 | 2 | 3 | 2 | 2 | 3 | 4 | 4 |
| Housing-relted CM | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 22 | 33 | 25 | 37 | 28 | 15 | 20 | 17 | 19 | 16 | 30 | 19 | 38 | 55 | 55 |
| **Industrial Minerals&Ores** | 55 | 56 | 51 | 47 | 44 | 51 | 59 | 53 | 55 | 61 | 57 | 54 | 57 | 68 | 69 | 69 | 66 | 67 | 68 | 65 | 64 | 64 |
| Non-metallic minerals | 4 | 5 | 4 | 3 | 2 | 3 | 4 | 0 | 0 | 4 | 0 | 3 | 2 | 4 | 3 | 4 | 5 | 5 | 6 | 4 | 2 | 2 |
| Metal Ores | 51 | 51 | 47 | 44 | 42 | 48 | 54 | 53 | 55 | 56 | 57 | 51 | 55 | 64 | 66 | 64 | 61 | 62 | 62 | 62 | 62 | 62 |
| **Total** | 206 | 238 | 229 | 201 | 190 | 189 | 234 | 211 | 231 | 220 | 244 | 237 | 217 | 247 | 248 | 263 | 276 | 298 | 291 | 308 | 328 | 325 |

| DE (%) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 23 | 20 | 21 | 26 | 29 | 29 | 24 | 29 | 26 | 28 | 25 | 27 | 28 | 26 | 25 | 25 | 24 | 23 | 23 | 22 | 20 | 19 |
| Biomass | 18 | 16 | 16 | 19 | 21 | 19 | 15 | 17 | 17 | 17 | 17 | 18 | 20 | 19 | 21 | 21 | 21 | 21 | 23 | 23 | 23 | 24 |
| Construction Minerals | 33 | 41 | 40 | 32 | 27 | 25 | 35 | 29 | 33 | 27 | 35 | 33 | 25 | 28 | 26 | 28 | 30 | 33 | 31 | 34 | 38 | 37 |
| Industrial Minerals&Ores | 27 | 24 | 22 | 23 | 23 | 27 | 25 | 25 | 24 | 28 | 23 | 23 | 26 | 27 | 28 | 26 | 24 | 22 | 23 | 21 | 19 | 20 |
| **Total** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

| DE/cap (t/cap) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 2.2 | 2.2 | 2.2 | 2.3 | 2.4 | 2.3 | 2.4 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.4 | 2.5 | 2.4 | 2.5 | 2.5 | 2.6 | 2.5 | 2.3 | 2.2 | 2.1 |
| Biomass | 1.8 | 1.7 | 1.7 | 1.7 | 1.7 | 1.6 | 1.5 | 1.5 | 1.6 | 1.6 | 1.6 | 1.7 | 1.7 | 1.8 | 2.0 | 2.1 | 2.2 | 2.3 | 2.4 | 2.5 | 2.6 | 2.6 |
| Construction Minerals | 3.2 | 4.6 | 4.2 | 2.9 | 2.3 | 2.1 | 3.5 | 2.5 | 3.2 | 2.5 | 3.4 | 3.1 | 2.1 | 2.6 | 2.5 | 2.8 | 3.1 | 3.6 | 3.2 | 3.7 | 4.2 | 4.0 |
| Industrial Minerals&Ores | 2.6 | 2.6 | 2.3 | 2.1 | 1.9 | 2.2 | 2.5 | 2.2 | 2.3 | 2.5 | 2.3 | 2.1 | 2.2 | 2.6 | 2.7 | 2.6 | 2.5 | 2.4 | 2.4 | 2.3 | 2.2 | 2.1 |
| **Total** | 9.8 | 11.1 | 10.4 | 9.0 | 8.3 | 8.2 | 9.9 | 8.8 | 9.5 | 8.9 | 9.8 | 9.4 | 8.5 | 9.6 | 9.5 | 9.9 | 10.3 | 10.9 | 10.5 | 10.8 | 11.2 | 10.9 |

**Appendix .3** Data Summary

Imports (IMP), Million tonnes (Mt)

| IMP (Mt) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fossil Fuels** | 12 | 8 | 10 | 5 | 2 | 3 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Natural Gas | 2 | 2 | 5 | 2 | 1 | 3 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Crude Oil | 9 | 5 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Biomass** | 5 | 5 | 3 | 4 | 2 | 2 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 4 | 4 |
| Primary crops | 5 | 5 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Semi&finished products | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Wood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| **Construction Minerals (CM)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Minerals for construction | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Semi&finished products | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Industrial Minerals&Ores** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 |
| Non-metallic minerals | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| Semi&finished products | | | | | | | | | | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Total** | **18** | **13** | **14** | **8** | **3** | **6** | **4** | **2** | **3** | **7** | **6** | **4** | **6** | **5** | **5** | **5** | **7** | **7** | **7** | **7** | **8** | **7** |

| IMP (%) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 69 | 59 | 75 | 55 | 46 | 59 | 59 | 40 | 56 | 23 | 26 | 25 | 27 | 23 | 19 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Biomass | 31 | 41 | 25 | 45 | 54 | 41 | 41 | 60 | 44 | 23 | 21 | 23 | 20 | 21 | 28 | 43 | 46 | 49 | 48 | 48 | 56 | 58 |
| Construction Minerals | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 13 | 15 | 19 | 22 | 25 | 27 | 22 | 16 | 17 | 19 | 16 | 6 |
| Industrial Minerals&Ores | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39 | 40 | 37 | 34 | 34 | 28 | 28 | 31 | 34 | 34 | 32 | 28 | 35 |
| **Total** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** | **100** |

| IMP/cap (t/cap) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 0.6 | 0.4 | 0.5 | 0.2 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Biomass | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.1 |
| Construction Minerals | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Industrial Minerals&Ores | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| **Total** | **0.8** | **0.6** | **0.6** | **0.4** | **0.1** | **0.3** | **0.2** | **0.1** | **0.1** | **0.3** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.2** | **0.3** | **0.3** | **0.3** | **0.3** | **0.2** |

**Appendix .4** Data Summary

Exports (IMP), Million tonnes (Mt)

| EXP (Mt) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fossil Fuels** | 3 | 3 | 6 | 4 | 5 | 9 | 9 | 6 | 6 | 6 | 6 | 4 | 7 | 9 | 10 | 11 | 12 | 12 | 13 | 12 | 10 | 9 |
| Natural Gas | 2 | 3 | 6 | 4 | 5 | 7 | 8 | 4 | 5 | 6 | 6 | 4 | 6 | 8 | 10 | 10 | 12 | 12 | 12 | 12 | 10 | 8 |
| Crude Oil | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Coal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Biomass** | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| Primary crops | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Semi&finished products | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wood | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Construction Minerals (CM)** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 |
| Minerals for construction | | | | | | | | | | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Semi&finished products | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Industrial Minerals&Ores** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Non-metallic minerals | | | | | | | | | | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| Semi&finished products | | | | | | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| **Total** | 5 | 4 | 7 | 6 | 7 | 9 | 11 | 7 | 7 | 8 | 8 | 6 | 9 | 12 | 14 | 14 | 16 | 15 | 15 | 16 | 13 | 12 |

| EXP (%) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 73 | 71 | 89 | 72 | 79 | 90 | 87 | 84 | 83 | 77 | 76 | 68 | 73 | 69 | 75 | 74 | 76 | 82 | 82 | 76 | 75 | 73 |
| Biomass | 27 | 29 | 11 | 28 | 21 | 10 | 13 | 16 | 17 | 16 | 12 | 17 | 11 | 14 | 12 | 12 | 9 | 5 | 5 | 6 | 8 | 9 |
| Construction Minerals | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 6 | 9 | 9 | 8 | 9 | 8 | 7 | 7 | 10 | 8 | 8 |
| Industrial Minerals&Ores | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 9 | 7 | 8 | 5 | 6 | 7 | 6 | 6 | 8 | 9 | 9 |
| **Total** | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

| EXP/cap (t/cap) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 0.2 | 0.1 | 0.3 | 0.2 | 0.2 | 0.4 | 0.4 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.4 | 0.3 | 0.3 |
| Biomass | 0.1 | 0.1 | 0.0 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Construction Minerals | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Industrial Minerals&Ores | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.3 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.4 |

**Appendix .5** Data Summary

Domestic Material Consumption (DMC), Million tonnes (Mt)

| DMC (Mt) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 55 | 51 | 53 | 52 | 51 | 49 | 50 | 56 | 57 | 56 | 57 | 61 | 56 | 56 | 53 | 55 | 55 | 58 | 56 | 55 | 54 | 54 |
| Biomass | 34 | 34 | 34 | 34 | 34 | 32 | 30 | 31 | 32 | 33 | 34 | 37 | 42 | 44 | 48 | 53 | 54 | 59 | 62 | 66 | 71 | 74 |
| Construction Minerals (CM) | 67 | 98 | 92 | 64 | 52 | 48 | 82 | 61 | 77 | 62 | 85 | 77 | 54 | 68 | 65 | 74 | 84 | 100 | 89 | 104 | 124 | 119 |
| Industrial Minerals&Ores | 55 | 56 | 51 | 47 | 44 | 51 | 59 | 53 | 55 | 63 | 59 | 55 | 59 | 69 | 70 | 69 | 67 | 68 | 69 | 66 | 65 | 65 |
| Total | 212 | 240 | 229 | 197 | 180 | 180 | 221 | 201 | 221 | 214 | 236 | 230 | 211 | 237 | 236 | 251 | 261 | 284 | 276 | 292 | 315 | 313 |

| DMC (%) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 26 | 21 | 23 | 26 | 28 | 27 | 23 | 28 | 26 | 26 | 24 | 26 | 27 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 17 | 17 |
| Biomass | 16 | 14 | 15 | 17 | 19 | 18 | 14 | 15 | 14 | 15 | 15 | 16 | 20 | 18 | 20 | 21 | 21 | 21 | 23 | 23 | 23 | 24 |
| Construction Minerals | 32 | 41 | 40 | 33 | 29 | 26 | 37 | 30 | 35 | 29 | 36 | 34 | 26 | 29 | 27 | 30 | 32 | 35 | 32 | 36 | 39 | 38 |
| Industrial Minerals&Ores | 26 | 23 | 22 | 24 | 24 | 28 | 27 | 27 | 25 | 29 | 25 | 24 | 28 | 29 | 30 | 28 | 26 | 24 | 25 | 23 | 21 | 21 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

| DMC/cap (t/cap) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 2.6 | 2.4 | 2.4 | 2.3 | 2.2 | 2.1 | 2.1 | 2.3 | 2.3 | 2.3 | 2.3 | 2.4 | 2.2 | 2.2 | 2.0 | 2.1 | 2.1 | 2.1 | 2.0 | 1.9 | 1.9 | 1.8 |
| Biomass | 1.6 | 1.6 | 1.5 | 1.5 | 1.5 | 1.4 | 1.3 | 1.3 | 1.3 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 2.0 | 2.0 | 2.1 | 2.3 | 2.3 | 2.4 | 2.5 |
| Construction Minerals | 3.2 | 4.6 | 4.2 | 2.9 | 2.3 | 2.1 | 3.5 | 2.5 | 3.2 | 2.5 | 3.4 | 3.1 | 2.1 | 2.6 | 2.5 | 2.8 | 3.1 | 3.6 | 3.2 | 3.7 | 4.2 | 4.0 |
| Industrial Minerals&Ores | 2.6 | 2.6 | 2.3 | 2.1 | 1.9 | 2.2 | 2.5 | 2.2 | 2.3 | 2.6 | 2.4 | 2.2 | 2.3 | 2.7 | 2.7 | 2.6 | 2.5 | 2.5 | 2.5 | 2.3 | 2.2 | 2.2 |
| Total | 10.1 | 11.2 | 10.5 | 8.8 | 7.9 | 7.7 | 9.3 | 8.3 | 9.1 | 8.7 | 9.4 | 9.1 | 8.2 | 9.2 | 9.0 | 9.5 | 9.7 | 10.4 | 10.0 | 10.2 | 10.7 | 10.5 |

**Appendix .6** Data Summary

Physical Trade Balance (PTB), Million tonnes (Mt)

| PTB (Mt) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 9 | 5 | 4 | 0 | -4 | -5 | -7 | -5 | -4 | -4 | -5 | -3 | -5 | -7 | -9 | -11 | -12 | -12 | -13 | -12 | -10 | -8 |
| Biomass | 4 | 4 | 3 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | -0 | 0 | -1 | -0 | 1 | 1 | 3 | 3 | 2 | 3 | 3 |
| Construction Minerals (CM) | | | | | | | | | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0 | 0 | -1 |
| Industrial Minerals&Ores | | | | | | | | | | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 |
| Total | 13 | 9 | 7 | 3 | -4 | -4 | -7 | -4 | -4 | -0 | -2 | -2 | -3 | -7 | -9 | -9 | -10 | -8 | -8 | -9 | -5 | -4 |

| PTB/cap (t/cap) | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fossil Fuels | 0.4 | 0.2 | 0.2 | 0.0 | -0.2 | -0.2 | -0.3 | -0.2 | -0.2 | -0.2 | -0.2 | -0.1 | -0.2 | -0.3 | -0.4 | -0.4 | -0.5 | -0.5 | -0.5 | -0.4 | -0.3 | -0.3 |
| Biomass | 0.2 | 0.2 | 0.1 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.0 | 0.0 | -0.0 | -0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Construction Minerals | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.0 | 0.0 | -0.0 |
| Industrial Minerals&Ores | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Total | 0.6 | 0.4 | 0.3 | 0.1 | -0.2 | -0.2 | -0.3 | -0.2 | -0.2 | -0.0 | -0.1 | -0.1 | -0.1 | -0.3 | -0.3 | -0.3 | -0.4 | -0.3 | -0.3 | -0.3 | -0.2 | -0.1 |

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