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The causes of the high energy intensity of the Kazakh economy: A characterization of its energy system

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A B S T R A C T

The primary energy intensity of Kazakhstan is among the highest in the world. The aim of this paper is to explore, in a quantitative way, the reasons for this condition, and to highlight the opportunities for improvement. To do so, we have developed a detailed 'bottom-up' model of the Kazakh energy sector. With this model, we have calculated the potential energy savings on both the demand and supply sides, and for all the economy sectors. This potential is defined as the difference between the current energy consumption in each sector/activity and the energy consumption if best available technologies or energy efficiency standards prevailing in developed countries were adopted in Kazakhstan. We conclude that the main causes of the energy inefficiency in Kazakhstan are: the excessive energy demand of buildings (especially for space heating) in the household and service sector, the inefficiency of the industry sector, particularly in the iron and steel and non-ferrous metals subsectors, the obsolescence of the heating and power generation assets, and the inefficient management of associated gas (flaring and re-injection in oil wells). With current energy efficiency standards prevailing in developed countries, the primary energy consumption in Kazakhstan in 2010 would be reduced by 48.6%, from 75.4 to 38.7 Mtoe.

1. Introduction

Kazakhstan is a landlocked country located between Europe and China. It ranks 9th in the world by size, although 62nd by population. For much of the twentieth century, Kazakhstan was part of the Union of Soviet Socialist Republics (USSR). It became independent in 1991, after the break-up of the USSR. The disintegration of the USSR resulted in financial, administrative, governance and political turmoil for most of the new independent states, which led to deep economic recessions in the region. Kazakhstan was not alien to this process and suffered an important economic decline, its Gross Domestic Product (GDP) in 1998 being 60% that of 1990. However, in the last decade, Kazakhstan has experienced strong economic growth, with GDP increases of nearly 10% most years. In 2011, the GDP growth was 7.5% [1]. This vigorous economic growth has been driven mainly by the exploitation of the country's natural resources. Kazakhstan is endowed with significant fossil fuel resources, uranium and minerals (copper, lead, zinc, iron ore, chromium). At the end of 2011, the oil reserves to production (R/P) ratio was 44.7 years, the gas R/P ratio was 97.6 years and the coal R/P ratio was 290 years [2]. The uranium reserves were around 12% of the world's identified ones [3]. In 2010, the Kazakh energy exports were 22% higher than its primary energy consumption [4]. And it is expected that Kazakhstan will become one of the world's top 10 oil producers by the end of this decade [5].

Despite this large endowment with natural resources, and the thriving oil subsector, the overall situation of the Kazakh energy sector is far from optimal. The power plants are old and inefficient, with nearly, 80% of the power plant capacity being older than 20 years [6]. Further, 58% of the total installed thermal power-generation capacity will reach the end of its lifetime by 2015 [7]. The situation is alike in the district heating sector. Up to 70% of heat generation, transmission and distribution assets are obsolete [8]. An energy indicator which reflects the problems of the Kazakh energy sector is its primary energy intensity, defined as the primary energy consumed to generate a unit of GDP. This is one of the highest in the world, even once the development level of Kazakhstan is accounted for, as revealed by the international benchmarking presented in Fig. 1. The high primary energy intensity of former USSR countries is well known [6,9]. Cornillie and Frankhauser [9] studied the energy intensity in transition countries through the decomposition of energy consumption. They concluded that inadequate energy tariffs (below cost-recovery levels) and the lack of enterprise restructuring and governance

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Nomenclature

$APEN_{A,i}$	penetration of an appliance A in i = urban or rural areas (number of units per household)
AVS	gross value added of the service sector (2000$)
$DTRA_{M,j}$	transport demand for modality M for j = passenger or freight (pax-km or tonne-km)
$EAGR^V$	demand of energy vector V in the agriculture sector (toe/year)
$EAPP^E_A$	household electricity demand for appliance A (kWh/year)
$EHOU^V_S$	household demand of energy vector V (toe/year) for an end-use service S
$EIND^V$	demand of energy vector V in the industry sector (toe/year)
$ESER_{S,i}$	final energy demand per person for end-use service S in i = urban or rural areas (toe/inhabitant/year)
$ESER^V$	demand of energy vector V in the service sector (toe/year)
$ETRA^V_M$	demand of energy vector V for transport modality M (toe/year)
INT^V	specific energy intensity in the service sector of energy vector V (toe/2000$)
INT^V_t	energy intensity of transport technology t using energy vector V (toe/pax-km or toe/tonne-km)
$NHOUSE_i$	total number of households in i = urban or rural areas (number of households)
POP_i	population (inhabitants) in i = urban or rural areas
$PROD_p$	annual production of product p or annual surface dedicated to crop p (t/year) or (ha/year)
SEC^V_p	specific consumption of energy vector V in the production of product p (toe/t or toe/ha)
$SPEC_A$	specific energy consumption of an appliance A (kWh/year)
$TEFF^V_{S,i}$	efficiency of the technology used to transform energy vector V for the end-use service S in i = urban or rural areas (%)
$TSHRE^V_{S,i}$	share of an energy vector V to meet the overall energy demand of end-use service S in i = urban or rural areas (%)
$VSHRE_{t,M,j}$	share of transport demand for modality M met with transport technology t for j = passenger or freight transport (%)

Abbreviations

ASRK	Agency of Statistics of the Republic of Kazakhstan
BAT	Best Available Technology
BPT	Best Practice Technology
CHP	Combined Heat and Power
CDD	Cooling Degree Days
CIS	Commonwealth of Independent States
GDP	Gross Domestic Product
GGFR	Global Gas Flaring Reduction
HDD	Heating Degree Days
HOB	Heat Only Boilers
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
LEAP	Long-range Energy Alternatives Planning System
LPG	Liquefied Petroleum Gas
OECD	Organisation for Economic Co-operation and Development
R/P	Reserves to Production ratio
UNECE	United Nations Economic Commission for Europe
UNIDO	United Nations Industrial Development Organization
USSR	Union of Soviet Socialist Republics
WRF	Weather Research Forecast

Units

kJ	kilojoule
m^2	square meter
kWh	kilowatt-hour
toe	tonne oil equivalent (=4.18 $\cdot$ 10^{10} Joules)
ktoe	kilotonne of oil equivalent (=4.18 $\cdot$ 10^{13} Joules)
Lm	lumens
Mt	million tonne
Mtoe	million tonne of oil equivalent (=4.18 $\cdot$ 10^{16} Joules)
MW	megawatt
pax-km	passengers times kilometers
tonne-km	tonnes times kilometers
TWh	terawatt hours
W	watt

reforms (such as privatization or power sector reform) were the two most important causes for the high primary energy intensity in these countries. Recently, Sarbassov et al. [17] used TIMES–MARKAL (The IntegratedMarket allocation Energy flow optimization model System) to investigate the potential energy savings in the residential and commercial sectors in Kazakhstan. They analyze several pathways to increase the efficiency of power and heat generation and distribution, and measures (mainly the use of meters) to foster energy efficiency. They conclude that the electricity and heat supplied to these residential and commercial sectors can be reduced by 1.3–1.5 Mtoe by 2030 (or nearly 30% of the current consumption) and the efficiency of the power and heat sector can be increased by 1.8–2.2% annually between 2010 and 2030. Other than these studies, few works have addressed specifically this issue for former Commonwealth of Independent States (CIS) countries.

The purpose of this paper is to find out the reasons for the energy inefficiency in Kazakhstan, and the room for improvement in the several subsectors of the economy. To do this, we have built a bottom-up model of the Kazakh energy sector where the demand and supply sides have been represented in great detail. This model reproduces the energy consumption data of Kazakhstan in 2010, but also offers, through the use of modeling, more detailed information than it is afforded by national statistics. This allows us to compare the energy efficiency of each sector with the corresponding one in developed countries, and to estimate the energy saving potential in Kazakhstan. To do so, we have implemented in the model the energy efficiency standards of developed countries (such as best available technologies). The energy saving potential is calculated as the difference between the energy consumption in Kazakhstan in 2010 and the resulting one if these efficiency standards of developed countries were applied.

Generally speaking, two methodologies are used in the scientific literature to calculate the energy saving potential: the top-down method and the bottom-up one. The former is based on the statistical analysis of aggregate energy and economic data. The second one, which is the one used in this work, calculates the difference between the current specific energy consumption of each process (energy transformation, distribution and end use) across the economy, and the one resulting from the application of energy efficiency measures.