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ANALYSIS

Cooperation benefits of Caspian countries in their energy sector development

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A B S T R A C T

This paper studies the development possibilities of the energy systems of four Central Asia and Caspian countries. It explores options that improve their domestic energy efficiencies and increase their export of fossil energy commodities. Using the MARKAL-TIMES modelling tool, it represents their energy system with a bottom-up partial economic equilibrium growth model. With the help of scenario analyses, it evaluates the direct economic advantage of improving the domestic energy efficiencies. Furthermore it calculates the direct economic advantage of cooperation. It finds out that a new/different geo-economic attitude brings USD billions of annual economic benefits, particularly if the countries aim to differentiate their export routes, increase the amount of export and contribute to climate change mitigation.

1. Introduction

1.1. Energy in Central Asia

Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan – Central Asian Caspian countries, CAC – are endowed with abundant energy resources. In particular Uzbekistan (UZB) and Turkmenistan (TKM) are rich in natural gas, Azerbaijan (AZJ) oil, Kazakhstan (KZK) oil, coal and uranium. In 2009, the overall production of the area was around 145 million tonnes (Mt) of crude oil against a consumption of 35.3 Mt, and around 150 billion cubic meters (Bcm) of natural gas against a consumption of 100 Bcm (Table 1).

About 110 Million tonnes oil equivalent (Mtoe) and 40 Mtoe of natural gas were exported in 2009, mainly to, or through, the Russian Federation. If the present status is extrapolated to the future, CAC countries will not be able to take full advantage of their energy resources, which could be compatible with a large increase of both domestic consumption and exports. Taking full advantage of their future energy rents would increase the GDP of the CAC countries and their economic development prospects much more than at present [1].

The full exploitation of the overall production capacity would make the Area a "key player" in the fossil fuels export for the next few decades. This calls for the urgent need of investments and the agreement on a joint energy export-strategy towards external markets as well as among the Caspian countries themselves. As stated in a special report [2] by the National Bureau of Asian Research "What we have yet to see is cooperation among the different players in Central Asia pipelines in pursuit of convergent objectives, as opposed to competition for divergent interests."

This study aims to assess quantitatively the direct economic benefits of cooperation among CAC countries, under different development and policy assumptions. The evaluation is carried out with the help of an energy model of the four countries and the CAC area. The TIMES-CAC-4R model is built with the aim of:

- representing the structure and the mid-long-term development of the four domestic energy systems at the maximum level of detail made possible by the available information, with hundreds of existing and new energy technologies; the models should indicate the optimal mix of energy resources, the optimal level of investments in new infrastructures, the desirable level of energy efficiency in supply and demand, etc.;

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Table 1
Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan: energy resources and indicators.

Indicators	References	AZJ	KZK	TKM	UZB	Sum	China + India	World
Population (million, 2011)	[7]	9.1	16.6	5.1	29.3	60	2586	6958
Population density (cap/sqkm) (d)		111	6	11	69	–	144/411	13.5
GDP/capita, 2011 ($'2005ppp/cap)	[7]	8.9	11.6	8.3	2.9	6.7	5.4	10.1
Oil rents (+) (% GDP) (£)	[1]	34–62	26–37	16–41	3–10	–	–	–
Natural gas rents (+) (% GDP) (£)	[1]	3–12	2–8 (^)	22–85	15–91	–	–	–
Energy consumption, 2011 (toe/cap)	[7]	1.4	4.7	4.8	1.6	2.7	1.3	1.9
CO2 emissons, 2011 (tco2/cap)	[7]	2.9	14	12	3.8	7.2	3.8	4.5
Crude oil (%)								
Ultimate recoverable resources (Billion of bbl)	[8–10]	15	71	19	3	108	57	3000
Reserves (Billion of bbl)	[8–12]	7	35 (*)	0.6 (a)	0.6	43 (*)	35	1480
Domestic consumption (2009, million of bbl/a)	[13]	70.8	118	60.0	21.6	270	3770	30,950
Net export (2009, million of bbl/a)	[13]	317	449	14.4	–	780	–	0
Natural gas								
Ultimate recoverable resources (Tcm)	[8–10]	4.5	7.2	11.8c	3.4	26.9	9.4	425
Reserves (Tcm)	[8–10]	>0.85	>3.5	>7.4 b	>1.8	>13.5	3.1	180
Domestic consumption (2009, in Bcm/a)	[13]	10.4	20.3	18.0	43.8	92.5	120	3114
Net export (2009, in Bcm/a)	[13]	5.8	6.9	19.1	12.7	44.5	–	0

Footnotes: (*) average over the range 30–40 B.bbl found in the literature; (+) as defined in the WB data base, rents are the difference between the value of oil/natural gas production at world prices and total costs of production; (£) 2000–2011 range; (^) coal rents ranged around 3–9% of GDP; (%) Domestic consumption and net export refer only to crude oil; if oil products are added, both values are similar to the values shown in the following tables; (a) plus 1.1 B.bbl of proved plus probable reserves in the Caspian Sea [14]; (b) according to BP, the proven reserves of natural gas in TKM were estimated 24 Tcm at the end of 2011 [11] and 17.5 Tcm at the end of 2012 [12]; (c) according to [15] the ultimate recoverable resources in the Galkinish-Yolotan fields are 26 Tcm, to make a total for TKM of more than 28 Tcm; (d) 144 relates to China, 411 relates to India.

- representing comprehensively the trade infrastructures and the flows level among the 4 CAC countries, in order to understand their optimal level under different development and policy assumptions; and
- more specifically exploring some "predefined size" investment possibilities in oil and gas pipelines.

As far as the authors are aware of, details on consumption by end use service have never been developed, and are not available in the literature. Furthermore, there have been no such models so far for the area and the CAC countries, except Kazakhstan [3].

Previous studies (Bilgin [4], The Regional Environmental Centre for Central Asia (CAREC) [5], and Babali [6]) focussed on the prospects of alternative energy corridors for the Caspian hydrocarbon resources and the possible room for cooperation from a geostrategic point of view and following a "what-if" approach, without any evaluation of the dynamic domestic energy demands and of the costs for the energy sector development. This is the first instance that the Caspian Region energy sector is modelled with detailed representation of both supply and demand sides (bottom-up approach), and with the technological descriptions of the existing mix of plants, demand devices, and industrial chains, in a base year and over 20 years of analysis.

This paper focusses on the potential synergies among the four Caspian nations in a quantitative manner, with a special focus on the development of natural gas and crude oil interregional trades. The second part of Section 1 illustrates the present energy consumption levels of the four countries. Section 2 outlines the main characteristics of methods, models and the scenarios, and Section 3 shows some key results of the analysis.

1.2. Energy trade flows and infrastructures

In the Soviet Union period the Caspian region was able to export only to the Russian Federation and through the state-controlled Russian pipelines system, mainly through the Druzhba oil pipeline system and the Soyuz gas pipeline system. After independence in 1991, Azerbaijan and Kazakhstan partly untied from the Russian Federation. They constructed the 1.2 Mbbl/d Baku-Tbilisi-Ceyhan pipeline (BTC, from Azerbaijan via Georgia to the Turkish coast) and the Caspian Pipeline Company's pipeline (0.7 Mbbl/d) from Atyrau in Kazakhstan to Novorossiysk in Russia. The former allows a complete bypass of the Russian territory, the latter of the Russian ownership. In 2009 about 80% of the Kazakh export still passed through the Russian Federation (via Novorossiysk or Samara). Export of Kazakh oil to China started only in 2006, but with relatively small flows due to capacity limitations in Kazakhstan – an additional connecting branch needs completion – and in China – to receive and distribute more oil.

Export of Central Asia's gas is even more dependent on Russia's control. About 90% of the total export of the area went through Russia until 2009, mainly via the Central Asia–Centre pipeline system crossing Turkmenistan, Uzbekistan and Kazakhstan (CAC pipeline), with a combined capacity of 40 Bcm/a. Azerbaijan is the only CAC country that can export natural gas independently from the Russian Federation, through Turkey via the Baku-Tbilisi-Erzurum (BTE), up to a maximum volume of 6.5 Bcm/a. Recently the Central Asia – China gas pipeline started bringing Central Asian natural gas to East, highlighting China's interest for Central Asian energy resources[1].

2. Method: model and scenario analysis

2.1. Modelling approach

This scenario analysis uses an integrated 4-region energy model of Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan, called TIMES-CAC-4R. This bottom up technical-economic partial equilibrium model is built using the TIMES model generator developed by the Energy Technology Systems Analysis Program of the International Energy Agency [16].

The key-components of the single-region national TIMES models are the technologies for the production of primary and secondary commodities (supply side) together with the most representative appliances and devices of the demand sectors. Each model represents separately about 30 demand sectors, as many as shown in the consumption part of the national balances. The main demand drivers, along with the resulting projection of the weighted aggregate demand

[1] Gas from the transit Countries might sum to the amount from Turkmenistan and increase the overall export via the Central Asia–China corridor.

Table 2
Technical-economic characterisation of the main renewable sources for electricity generation.

	Investment cost in 2030	Technical potential in 2030 (in GW)			
	In CAC (US$'2000ppp/kW)	AZJ	KZK	TKM	UZB
Hydro	1500—5000 (*)	Limited, unexploited	6	Limited	Limited, unexploited
Wind	1800	Negligible	25 (^)	10	negligible
Solar	1800—2200 (+)	unlimited in the model			
Geo	—	not available in the model till 2030			

Footnotes: (*) the range reflects the site dependency of costs, for both impoundment and run of the river plants; (+) the two extremes of the range refer to centralised and distributed systems; (^) up to 350 GW in the long term according to the Wind Atlas of Kazakhstan [18].

Table 3
Major development drivers and aggregate demand indexes.

	Indicator	Values	In 2009	Growth index (2009 = 100)		
				2020	2025	2030
AZJ	Population	Million	8.8	118	124	130
	GDP per capita (£)	US$'2000 ppp	8702	175	217	251
	Aggregate demand for energy services	Index (+)	100	199	265	328
KZK	Population	Million	15.9	118	124	130
	GDP per capita (£)	US$'2000 ppp	8400	161	196	238
	Aggregate demand for energy services	Index (+)	100	167	209	264
TKM	Population	Million	5.1	118	124	130
	GDP per capita (£)	US$'2000 ppp	9859	175	217	251
	Aggregate demand for energy services	Index (+)	100	179	226	269
UZB	Population	Million	27.8	118	124	130
	GDP per capita (£)	US$'2000 ppp	2395	175	217	251
	Aggregate demand for energy services	Index (+)	100	185	238	283
CAC	Population	Million	57.6	118	124	130
	GDP per capita (£)	US$'2000 ppp	5678	170	208	246
	Aggregate demand for energy services	Index (+)	100	178	226	278

Footnotes: (*) indexes are equal to 100 in the base year, 2009; (£) Source: IEA [19] (+) the growth of the 30—35 separate demands, which can be tons of cement or passenger * kilometres, are averaged using as weights their final energy consumption in the base year.

for energy services are reported in Table 3 [17] [2]. Domestically, energy service demands are expected to increase the consumption of oil products and natural gas up to 3—4 folds by 2030.

The time horizon of the models is 2050, but it is flexible and can be used for analysis in the medium term (until 2020 or 2030). Each single country model can run in a standalone mode.

In each country model domestic fossil energy resources — as shown in Table 1 — are available to supply[3]:

- the endogenous level of trade among the 4 CAC countries, and
- the exogenous levels of export to the rest of the world.

The technical potential and the investment cost of hydro, wind, solar PV and geothermal in the four single region models are reported in Table 2. For hydro, due to the limited potential, an almost flat upper bound is set in the model for all the countries. For wind, an almost flat upper bound of a few MW is set in the AZJ and UZB country models, due to their limited potential; the energy systems of KZK and TKM are allowed to use wind power up to their bounds on the basis of an economic competitiveness criterion. Since the potential for solar energy is huge in the four countries, the models do not impose upper limits: the use of solar is decided only on economic competitiveness basis. In this version of the models run to 2030, geothermal is not included, although UZB has a strong potential and TKM a moderate one.

The 4-region TIMES-CAC-4R model represents the Central Asian-Caspian energy system. It assembles the 4 separate but structurally consistent single-region TIMES country models by interconnecting them with endogenous trade infrastructures, energy flows and emission permits[4]. In other words in this model the resources of each country can be traded endogenously with all the other CAC countries. In the base year import and export flows through the existing infrastructure are reproduced by the model for each country.

The model includes the possibility to build new infrastructures, as listed in Table 4, and increase the exchanges within the CAC area and the export to external markets. In particular, the Trans-Caspian Oil Transport System is a proposed project to transport oil through the Caspian Sea from Kazakhstani Caspian oilfields to Baku in Azerbaijan for the further transportation to the Mediterranean or Black Sea coast. The main options under consideration are an offshore oil pipeline from Kazakhstan to Azerbaijan[5], and construction of oil terminals and an oil tankers fleet[6]. New natural gas infrastructures are allowed to be built to increase the capacities of existing corridors with parallel lines (TKM-China, TKM-Russian Federation) or to open new and alternative energy corridors (Trans-Caspian Gas Pipeline TKM-AZJ). The level of capacity and its flows are fully endogenous. Investments in new trade-capacities are allowed starting from 2015.

This particular model makes use of the "lumpy investment variant" of TIMES[7]. Since pipelines have to be built with a predefined capacity, the variable representing them in the TIMES-CAC-4R model cannot be continuous as in normal LP models. They are declared as integer: the model can choose among 3 or more capacities when a new pipeline is necessary[8].

Integer variables represent new investments in trade infrastructures: four "unidirectional" cross-regional trades of natural gas and three "unidirectional" cross-regional trades of oil. The main technical economic characteristics of each trade connection are reported in Table 4.

Linear variables represent four "bidirectional" cross-regional trades of electricity and two unidirectional cross-regional trades of coal. Coal for power plants is exported from KZK to TKM at a price of 53 $'2000/t corresponding to a distance of about 3000 km and to UZB at a price of 45 $'2000/t corresponding to a distance of 2000 km. For smaller consumers the price is 1.5 times higher. Building new high voltage lines to

[2] These projections are not forecasts, but rather instruments used to carry out quantitative scenario analyses.

[3] The possibility to increase supplies in the first few years is limited in order to wait for the new extraction infrastructure to be build. For instance in the years 2015—2020 the extraction of natural gas is limited to 850 Bcf in AZJ, 3000 Bcf in TKM, and to very little growths over the base year values are permitted in UZB.

[4] Data about existing, under construction, and planned infrastructure projects, information about bilateral agreements on energy issues, criticalities of export routes, geopolitical and geostrategic overviews of the Area and of the players are taken from Refs. [5, 22—26].

[5] The construction of this pipeline is facing the opposition of the Russian Federation and Iran, officially related to the legal status of the basin.

[6] A strong push for the project has come from the partners of the Kashagan oilfield project and in particular TOTAL who has a share in both the field and the BTC pipeline. Apparently, KZK already started to transport oil from Tengiz via tankers across Caspian.

[7] This model variant is explained in TIMES Documentation, PART I, chapter 7 [16].

[8] The TIMES-CAC-4R model is solved using the mixed-integer-linear programming (MILP) option of the CPLEX solver of ILOG. The model has about 164,000 equations, 195,000 variables and one million non-zero elements. The linear variant solves in a minute or two in a work station. Having about 50 integer variables, multiplies the solution time by a factor of 3—4.

Table 4
New possible pipelines: main characteristics in the TIMES-CAC-4R model.

Main characterisation parameters (*) (**) →: New oil pipelines, among the 4 CAC countries (+)		Approx. length, *km*	Capacities *(M. bbl/day)*	Investment cost *M$'2000/(PJ/a)*	Annual flows *PJ/a*	Var.O&M cost M$'2000/PJ
KZK-TKM		700	0.05/0.1/0.24	8/12/16	100/200/500	1
KZK-UZB		500	0.1/0.2/0.5	6/10/14	200/400/1000	1
Non-CAC transit Countries (++)						
New oil pipelines, with the rest of the world						
KZK-MED sea, via AZJ (^) (&)	GEO, TUR	1500	0.24/0.72/1.2	18/22/26	480/1440/2400	1
New gas pipelines with the rest of the world			*(Bcm/a)*			
TKM-RF, through KZK	RF, UKR/BLR	2000	28.5/51.5/80	16/20/24	1000/1800/2800	4
TKM-CHI, through UZB/KZK	—	1500	24.5/30/35	16/20/24	850/1050/1250	3
TKM-CHI, through UZB/TJK/KYR	TAJ, KYR	1500	14/23/28.5	16/20/24	500/800/1000	3
TKM-MED sea, through AZJ	GEO, TUR	^1500	5.5/8.5/20	18/22/26	200/300/700	6

Footnotes: (*): Start year = 2015, Lifetime = 40y, Fixed O&M = 5% of the investment cost, own consumption: 0.9% for gas pipelines, 0.5% for oil pipelines; (**) data from Refs. [20]; (+): CAC = Central Asia Caspian, AZJ = Azerbaijan, KZK = Kazakhstan, TKM = Turkmenistan, UZB = Uzbekistan; (++): BLR = Bielarus, CHI = China, GEO = Georgia, KYR = Kyrgyzstan, RF = Russian Federation, TAJ = Tajikistan, TUR = Trurkey, UKR = Ukraine; ^ under the Caspian sea; it refers to the offshore oil pipeline from Kazakhstan to Azerbaijan; & associated with the possible expansion of the Baku—Tbilisi—Ceyhan pipeline (BTC) 0.5 M.bbl/d.

Table 5
Scenarios list and code names.

Drivers	Emission limits		High export increase	
	No	Yes	To West, via Russia	To West, via Mediterranean Sea
Cooperative	Ref	Ref_Emi	WRF_HE	WMS_HE
Non-cooperative	Ref_NC	Ref_Emi_NC	WRF_HE_NC	*Infeasible*

trade electricity among CAC countries has an average investment cost in the model of 740 M$'2000/GW, an efficiency of 96% and a fixed operation and maintenance cost of 7.4 M$'2000/GW[9].

2.2. Projection drivers and scenario assumptions

In this study the scenarios are meant to explore the direct economic advantage of cooperation policies in the energy and climate change mitigation sectors. The following cooperation policies in the area are directly modelled:

- exploitation of Caspian oil and natural gas resources;
- investment in the construction of new pipelines;
- maintenance of free exchange in the energy sector; and
- creation of a joint CO_2 emission permit system in the CAC area.

Different cooperation levels are tested. In the most cooperative scenarios, a new geo-economic attitude prevails in governments, not only in energy companies: the four countries agree among each other and with their neighbours in order to maximise the economic benefit of their large energy resources, by making them available to a much higher but still feasible level. This situation is modelled by making it possible to exploit Caspian oil and natural gas resources to their maximum technical availability. The number and size of new infrastructures is open to several possibilities, all of them with a cost of capital as low as the general discount rate, 5%. The level of customs duties across the four countries remains zero. In the field of climate change mitigation policy, the four countries decide to cooperate and open some sort of Emission Trading Scheme[10], in order to make it cheaper to achieve the mitigation objective of Kazakhstan, which is the only Annex I country in CAC with binding commitments[11].

At the other extreme, short sighted nationalistic policies prevail: national interests prevent the development of the two new large subsea trans-Caspian oil and gas pipelines; the remaining ones incur higher capital costs, with interest rates increasing up to 20% in 2030. Also the amount of low cost coal exported from KZK to UZB and TKM is reduced to zero and the construction of new power transmission lines banned. Furthermore, the Caspian disputes extend the uncertainties and reduce foreign investments on the development of important fields, with the effect of halving future extraction levels from new Caspian Sea fields. KZK is also assumed to comply with its mitigation commitments without the possibility to buy permits from the neighbouring CAC countries.

Total revenues will be exogenously calculated by assuming export prices (see Table 6), while the costs of the optimal configuration of the CAC system (new energy and technology mix to meet the additional export in the time horizon) will be completely endogenous. The direct economic value of cooperation (extra revenues minus extra costs) in the energy sector is evaluated and quantified by exploring different development possibilities as to[12]:

- amount of export,
- directions of export, and
- climate change mitigation commitments (of Kazakhstan).

The first driver is explored considering three oil and gas export levels:

- base: constant to the 2009 level of about 110 Mtoe of crude oil and about 40 Mtoe of natural gas;
- mid: natural gas increasing in 2030 by 42 Bcm/a and crude oil by 50 Mt/a above the base[13]; and
- max: natural gas increasing in 2030 by 62 Bcm/a and crude oil by 55 Mt/a above the base (HE).

[9] These average values are based on power system consideration and statistical data, assuming as a reference a 500 kV overhead transmission line of 1000 km with an overall cost of US$ 270 million or, a 500 kV undersea transmission line of 300 km at the same cost.

[10] International emission trading mechanisms, including Countries outside the borders of the CAC region, have not been taken into account in order to highlight the room of cooperation within the Area.

[11] For more info on the Kazakh climate change mitigation commitments and plans, see for instance [27].

[12] The cooperative/non-cooperative approaches are designed on the basis of the decision-science technique (mathematical programming) used for representing and solving the decision problem, which is characterized by a mono-objective function to optimize. A game-theory based analysis, multi-players and multi-objectives, aiming at identifying the most stable coalitions among the four countries, will be performed later for a comparative study.

[13] The mid export level case is not reported here.

Table 6
High export levels (HE) and possible revenues of the CAC region.

Unit revenue (*)	Unit (+)	China	Russia	Europe	Total	Unit (+)	China	Russia	Europe	Total
Expressed in	$/bbl	70	40	100		$/000 cm	175	70	280	
Max export scenario of	Crude oil					Natural gas				
To West-Russia										
Export levels (^)	Mbbl/d	0.15	0.95	0.00	1.10	Bcm/a	0	62.4	0	62.4
Revenues	$ Bill	3.9	13.8	0.0	17.7	$ Bill	0	4.4	0	4.4
To West-Mediterranean Sea										
Export levels (^)	Mbbl/d	0.15	0.42	0.53	1.10	Bcm/a	42.9	0	19.5	62.4
Revenues	$ Bill	3.9	6.1	19.2	29.3	$ Bill	7.5	0	5.5	13.0

Footnotes: (*) although used to build an example, these unit revenues are compatible with some market prices in recent years [21]; (+) $ means here USD constant of the year 2000; (^) amount of export in 2030 additional to the 2009 levels.

In order to assess the effect of increasing export in different directions, four alternative cases have been prepared: West through Russia using the Gazprom system (WRF), West through Azerbaijan to the Mediterranean Sea (WMS), East to China (CHI), and South to Iran (IRA)[14]. Fig. 1 displays the preferential "exit points" at the border of the TIMES-CAC-4R model area.

The climate change mitigation driver is explored by limiting the emissions of Greenhouse Gases (GHG) from the energy systems. In the base case, without mitigation policies, KZK increases its CO2 emissions from the energy system from 238 $MtCO_2eq/a$ in 2009 to 456 $MtCO_2eq/a$ in 2030, and the four countries together increase the sum of their CO_2 emissions from 483 $MtCO_2eq/a$ in 2009 to 921 MtCO2eq/a in 2030. In the mitigation scenarios (Emi), CO_2 emissions of the four energy systems together have to be limited to 670 MtCO2eq/a in 2030. In the cooperative case, KZK can purchase emission permits from the neighbours, and reduces its domestic emissions to 349 MtCO2eq/a in 2030; in the non-cooperative case, KZK has to reduce its domestic emissions down to 245 MtCO2eq/a in 2030, while the other three countries don't have any commitment and emit the complement to 670 MtCO2eq/a in 2030. The two scenarios differ by the possibility or not for KZK to buy permits from neighbouring countries.

This paper briefly discusses only the seven scenarios listed in Table 5.

3. Scenario results

3.1. A stationary export case

Assuming that the four countries develop with the present economic trend (see Table 3), if the 2009 level of oil and gas export remains constant through 2030, the total discounted system extra-cost[15] of non-cooperation (case Ref_NC) is about 2.3 billion USD2000, which is less of 0.2% of the total discounted value of the four energy systems from 2010 to 2030. The main looser in this case is UZB, which bears almost the entire losses of the four countries; it suffers extra-costs of about 1% of its total annual energy system cost, corresponding to about 0.5 billion USD2000 towards the end of the twenties.

Since UZB is tight in conventional oil and gas domestic resources, by 2030 it fully exploits its conventional oil resources and almost all its conventional natural gas resources already in the reference case. In the non-cooperative scenarios access to capital becomes more difficult and the amount of domestic oil and gas supply reduces below the levels needed to satisfy its growing demand for energy services in 2030.

In the case of natural gas, the gap cannot be filled by import since gas pipelines do not exist and cannot be built due to non-cooperation. The domestic consumption system shifts slightly from natural gas to coal where possible, like for instance in commercial space heating. Energy efficiency improvement is the solution in all other sectors: losses are reduced in the transport and distribution system of natural gas, electricity and district heat; better and new technologies are used in plants and demand devices (Fig. 2a). Prices increase (Fig. 2b, c) to the level that makes competitive the more efficient processes. As a result, the TPES needed in 2030 to satisfy the same demand for energy services reduce by 2.7%. In the case of oil, the gap is filled by importing crude from KZK to the maximum levels permitted by the existing pipeline, at a cost higher than in the reference case, because KZK imposes export duties (Fig. 2b, c). The amount of oil products used by final consumers does not change.

3.2. Increased export of oil and gas

Oil and natural gas industry contributes more to the growth of the domestic economies of the CAC countries if export increases to high but still reasonable levels (Table 6). For example, with unit revenues as exemplified in the above table, the total revenues of CAC countries exporting crude oil and natural gas could increase by more than 22 billion USD2000 (sum of crude oil + natural gas). If the preferential export routes to the Russian Federation are maintained, the direct annual cost of increasing export is 12 billion USD2000 for KZK, 2.5 billion USD2000 for UZB and 0.7 billion USD2000 for TKM, for a total of about 15 billion USD2000 per year in the twenties.

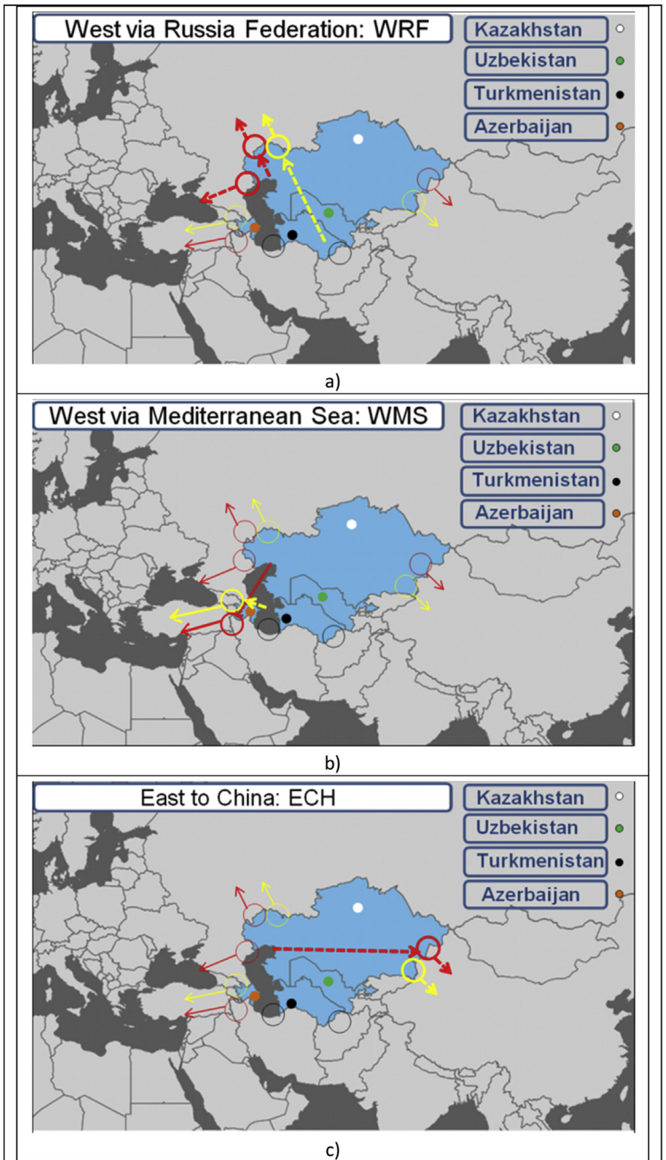
At such high export levels (HE) the cost of non-cooperation is higher than in the stationary case. Maintaining the preferential export routes to the Russian Federation till 2030, the total CAC discounted system extra-cost of non-cooperation (WRF_HE_NC) increases to more than 10 billion USD2000. In the twenties the average annual extra-cost is about

Table 7
New pipelines capacity endogenously built by the model by scenario (in PJ/a).

Pipeline	WRF			WMS		
Name	2020	2025	2030	2020	2025	2030
Direct gas export from AZJ to Med				343	355	355
Direct oil export from AZJ to Med				600	600	600
Direct oil export from KZK to China				322	322	322
Direct oil export from KZK to Russia	1540	1760	1980	880	880	880
Direct gas export from KZK to Russia	1140	1222	1310			
Gas export UZB-KZK (to Russia, 200)	2*200	2*200	2*200			
Gas export UZB-KZK (to Russia, 300)		1*300	1*300			
Gas export TKM-KZK (to Russia, 1000)	0	0	1*1000			
Gas export TKM-AZJ (to Med, 200)				1*200	1*200	2*200
Gas export TKM-UZB-KZK (to China, 850)				2*850	2*850	2*850
Oil export KZK-AZJ (to Med, 500)				1*500	1*500	2*500
Oil export KZK-UZB (200)		1*200	1*200		1*200	2*200

Footnotes: Direct exports have been modelled with "linear" decision variables, Cross-Country infrastructures with integer decision variables, whose size is specified in brackets.

[14] In fact the third (CHI) and fourth (IRA) alternative routes are not reported here.
[15] This total discounted cost, as well as all the others referred to in this paper, refers to the periods 2010-2030 and is discounted with a discount rate of 5% in real terms.



Bold = main export route; red color = crude oil flow; yellow color = natural gas flow.

Fig. 1. Three alternative export routes from Caspian Region; a) To the West via Russian Federation (WRF); b) To the West via Mediterranean Sea (WMS); c) To the East to China (ECH).

1.5 billion USD2000, 80% of which incurred by KZK, the rest by TKM. In both countries this extra-cost is 1.4% of the total discounted domestic energy system cost. The extra cost in KZK is due to the increase of oil extractions needed to meeting the additional demand of the market across the Russian oil pipeline system, and to more investments in energy efficiency needed to reduce domestic consumption and maintain the same export level. The extra cost in TKM is spent in extracting more natural gas to be sent to KZK and Russia through a new cross-country pipeline with a capacity of 30 Bcm/a, and substituting the lower import from UZB (Fig. 3). Thus in 2030, 100% of the oil export increase is covered by KZK, and 28% of the natural gas additional demand is covered by TKM.

3.3. New directions of export

If they cooperate, CAC countries can build an export route supplemental to the existing ones, through Georgia, Turkey and the Mediterranean Sea, and export higher but still reasonable levels of oil and natural gas (Table 6). Exporting higher amounts directly to Europe could be more economically profitable than continuing with the existing routes and less exposed to direct[16] socio-political transit country risks. With the indicative price assumptions of Table 6 the extra revenues would be of the order of 20 billion USD2000. With the assumptions used in this study, reaching this objective would imply annual average extra-cost of 12 billion USD2000 in the twenties. The capacity of existing corridors would be increased and new pipelines built (Table 7), and the CAC domestic energy systems should be adapted, in particular in AZJ (Fig. 4).

Non-cooperation has the direct effect of preventing the exploitation of Caspian offshore fields and the construction of sub-sea Caspian pipelines. In other words export from CAC to Europe via Turkey and the Mediterranean Sea cannot be increased much in the non-cooperative scenarios[17], since without the amount of oil and gas coming from the other three CAC countries, AZJ cannot increase its export and feed its increasing energy consumption at the same time, also because coal cannot be imported from KZK and electricity from the others[18].

3.4. Climate change mitigation commitments of KZK

Among the four CAC countries, only KZK committed to adopt climate change mitigation policies. No decisions have been taken beyond 2020; in this study we assume that GHG emissions from the energy system of KZK stabilise after 2020 to the 2010 levels (Fig. 5, scenario Ref_Emi_NC). Summing up the emissions of the other three countries, which are not committed to any limitation, a total of about 670 MtCO2eq is emitted by CAC countries in 2030. If the same limitation is applied to the four CAC countries together, KZK reduces its domestic effort and still achieves its commitments by purchasing quite substantial emission permits from the neighbours.

Assuming that the amount and direction of oil and gas export remain the same as in 2009, even a severe climate change mitigation policy by KZK looks affordable if it can trade emission permits with the AZJ, TKM and UZB. By comparing scenarios Ref and Ref_Emi, the total discounted system extra cost of mitigation would be about 15 billion USD2000, of which 11 billion USD2000 spent in KZK domestic policies and measure. The rest is the annual cost for purchasing emission permits from AZJ, TKM and UZB, for 0.2 billion USD2000, 0.3 billion USD2000 and 0.7 billion USD2000 respectively in 2030. In this win–win scenario KZK would provide funds for energy efficiency improvements of the four CAC countries (Fig. 5a).

In KZK the extra cost of 0.5 billion USD2000 in 2025 and 4 billion USD2000 for mitigation in 2030 is made up mostly of additional investments in the generation side where new oil and gas fired plants replace some old coal-fired units (Fig. 6a); additionally in the residential and tertiary sectors new end-use devices are used which reduce the consumption of coal and increase the use of natural gas up to 15% in the total final consumption.

If the neighbouring CAC countries do not cooperate, and KZK aims to achieve the same emission limitation and reduction targets to 2030, comparing scenarios Ref and Ref_Emi_NC, the total system extra-cost

[16] Any Trans-Caspian project would probably face the "indirect" risk of worsening relations with Russia.

[17] Technically, non-cooperative scenarios of increased export to the EU alternative to the Russian Federation routes are 'infeasible'.

[18] Oil and gas export from CAC to China can be increased to a mid-level, but not to the economic potential (high export levels used in the cooperative scenarios with exports to the Russian Federation or the Mediterranean Sea) if the countries do not cooperate. In the mid-level oil and gas export case, the lack of cooperation increases the total discounted system cost of the area by more than 100 USD2000. Two third of the burden is borne by AZJ with annual extra cost of almost 10 USD2000, one third by KZK with about 5 USD2000.

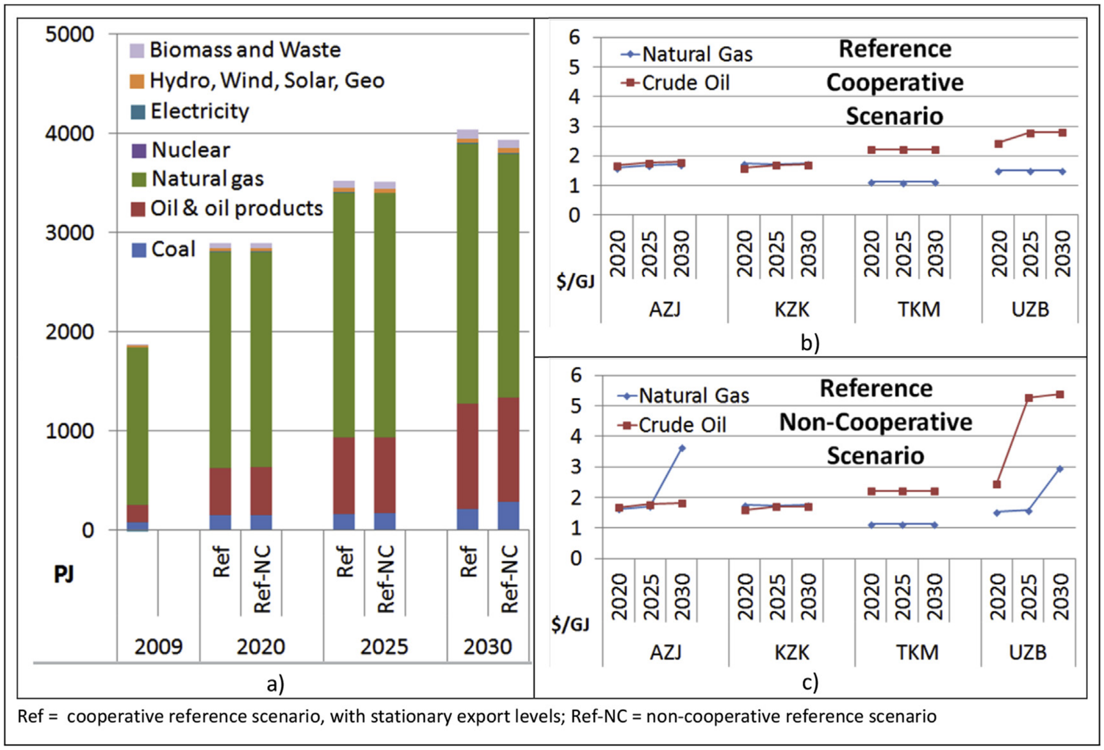


Fig. 2. a) Total primary energy supply (TPES) in Uzbekistan; b) and c) Energy prices in the Reference (REF) and Non-cooperative Reference (REF-NC) scenarios for all countries of the CAC region.

more than doubles to 33 billion USD2000, entirely borne by KZK. The annual extra cost for the KZK energy system would be about 1 billion USD2000 in 2020, 4 billion USD2000 in 2025, and 9 billion USD2000 in 2030, mainly in investments for low/no carbon technologies[19]. The cost is due mainly to the purchase and use of more efficient end use devices, which reduce the amount of final energy consumed to satisfy demands for energy services equal to the reference scenarios (Fig. 6b).

4. Discussions

The method of technical-economic growth models used in this paper assumes perfect markets. The results portray ideal system developments and identify 'optimal' decision strategies. However, particularly in the field of energy, mono/oligo-polistic and mono/oligo-psonistic behaviours determine sub-optimal decisions. Therefore the indications resulting from analyses of the type illustrated in this paper need further checking. In any case, the investment decisions suggested by model results need detailed Cost Benefit Analyses and multi-criteria assessment.

Many assumptions were necessary in order to represent the CAC country in energy systems models. The energy flow and technology stock data in the calibration look realistic, although far from certainty. The development assumptions are intermediate among the set of assumption found in the literature. Particular care has been used to keep realistic the energy export scenario assumptions.

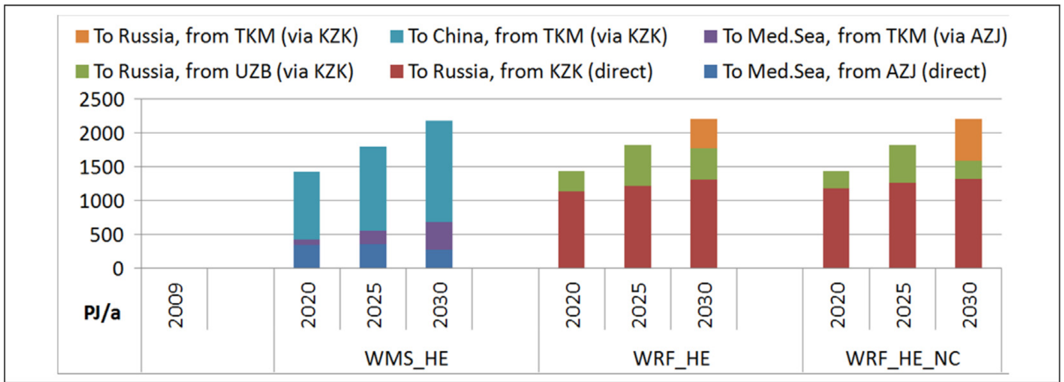
The models have been always used within a range not too far from the base growth path: scenarios with unrealistic marginal prices have been rejected. In this paper we prefer to show results which relate to differences among scenarios because they are much more robust than absolute values related to a single scenario.

Although using a different regional coverage and an economic approach extending to socio-political aspects, CAREC [5] posts investment figures of the same order of magnitude of the present studies. However the direct economic benefits illustrated in this paper are not simply calculated by subtracting to the revenues of oil and gas export the cost of supplying them. This paper takes a system approach and accounts also for the feedbacks to different policies: it includes in the evaluation the total costs of developing the domestic energy systems, from mining to end uses, given a set of assumptions on the availability of energy resources and future developments of demands for energy services. It shows the strength of carrying out energy policy evaluations using the approach of systems analysis and bottom-up technical-economic partial equilibrium growth models.

The method used in this paper calculates the direct economic benefits and cost of the energy systems. The actual economic benefits for the countries are much higher than the direct revenues from oil and gas export. Their estimate requires the use of appropriate consumer's and producer's multipliers, or even better the use of general equilibrium growth models.

Better evaluations will be carried out in the future when the TIMES-CAC model will include more technological options; for instance adding a finer definition of time slices to represent electricity and hydroelectric rich countries such as Kyrgyzstan and Tajikistan, the electricity trade pattern will become more realistic. Adding as separate regions the big surrounding countries — such as China, India, the Russian Federation and the Western European countries — will make export routes endogenous model variables and provide better results. A further step could be to switch to the general equilibrium version of TIMES, and/or to solve the decision problem making use of a game theory approach.

[19] The cost of mitigation increases if more oil and gas are exported (high export increase). In these cases less natural gas is available for domestic consumption, and more no/low carbon technologies have to be used, renewables sources and highly efficient plants and processes. In the non-cooperative scenarios, the corresponding cost of mitigation becomes 4-5 higher than the corresponding cooperation scenario, since natural gas is even scarcer.



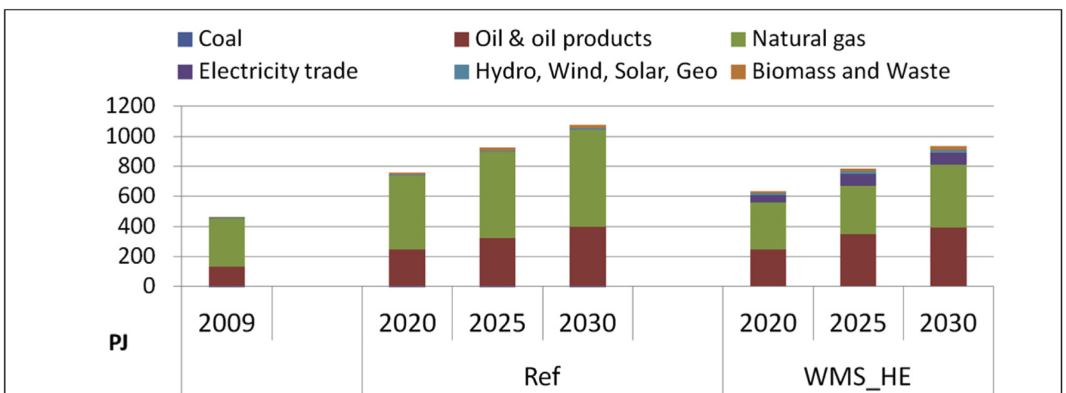
WMS_HE = cooperative scenario of High Export to Western Europe via Georgia, Turkey and the Meditarranean Sea; **WRF_HE** = cooperative scenario of High Export to Western Europe via the Russian Federeation; **WRF_HE_NC** = non-cooperative WRF_HE

Fig. 3. Origin of the natural gas exported from the CAC Area, by year and scenario.

5. Conclusions

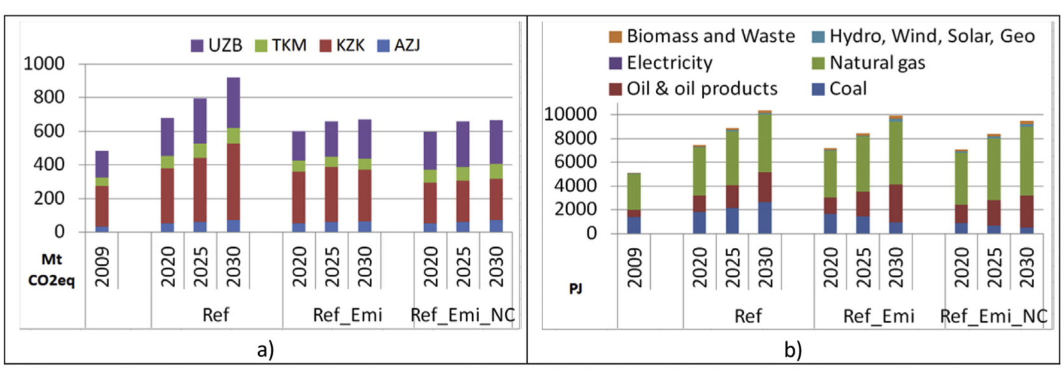
This analysis of four Central Asian Caspian countries — Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan — and their energy systems assumes that their transition towards a market economy continues and completes by 2030. With this assumption, the use of technical-economic equilibrium growth models underlines the importance of policies that achieve two objectives: the energy efficiency of the domestic systems and the maximum cooperation among the four countries.

The efficiency of the CAC energy system could increase from 51% in 2009 to 67% in 2030 if optimal investments and development strategies will be implemented. This would bring the efficiency of the system close to the present average global level of 68%. Moving in this direction



Ref = cooperative reference scenario, with stationary export levels; **WMS_HE** = cooperative scenario with high export levels to Western Europe, via Georgia, Turkey, Mediterranean Sea

Fig. 4. Total Primary Energy Supply (TPES) of Azerbaijan (AZJ) by year, energy form, and scenario.



Ref = cooperative reference scenario, with stationary export levels, without emission limitations; **Ref_Emi** = cooperative reference scenario, with stationary export levels and emission limitations on the CAC bubble; **Ref_Emi_NC** = Ref Emi non-cooperative

Fig. 5. a) GHG emissions of CAC Area by Country and scenario; b) Total Primary Energy Supply (TPES) of CAC Area by fuel.

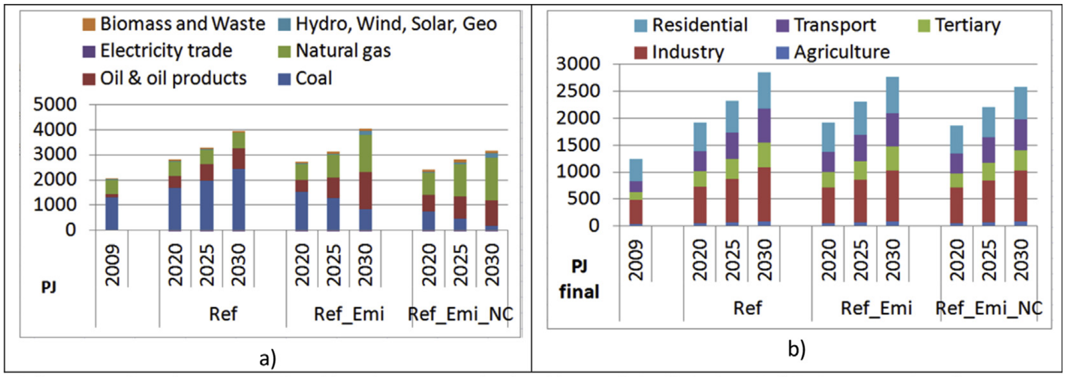


Fig. 6. a) Total Primary Energy Supply (TPES) of Kazakhstan by energy form and scenario; b) Total Final Consumption (TFC) of Kazakhstan by scenario and demand sector.

the cost of the domestic energy systems of CAC countries together would reduce of about 10 billion USD2000 per year in the period 2025—30.

Cooperation could bring similar if not higher benefits. At present the cooperation level among AZJ, KZK, TKM and UZB is not optimal due to unresolved issues related to the exploitation of Caspian crude oil and natural gas resources and the difficulty to agree on investments in the construction of new pipelines. In the future, nationalistic policies could worsen the situation and arrive to impose barriers to the free exchange of energy commodities. This study shows that cooperation among AZJ, KZK, TKM and UZB in the field of energy at large produces direct economic benefits[20] to the area under a wide range of scenario assumptions.

If no new policies are undertaken and crude oil and natural gas export remain constant at the 2009 level/directions till 2030 (stationary export case), the direct economic benefits of cooperation range around 0.5 billion USD2000 annually in the twenties. The direct economic benefits of cooperation increase if new policies are undertaken.

If the CAC countries increase their 2009 export level by 1.1 Mbbl/d of crude oil and 62 Bcm/a of natural gas (2300 PJ/a and 2200 PJ/a respectively), but maintain the same preferential export routes to the Russian Federation, the direct economic benefit of cooperation is in about 1.5 billion USD2000 per year in the twenties. Without cooperation, if the same export increase is preferentially conveyed to Western Europe through Georgia, Turkey and the Mediterranean Sea, the direct economic benefit is about 8 billion USD2000 annually in the twenties. Without cooperation such option could not be implemented.

Eventually, if KZK wants to implement a strong mitigation policy and keep its GHG emissions from the energy system constant to the 2010 level of about 240 MtCO2eq till 2030 the cooperation with the other CAC countries would reduce the Kazakh mitigation cost of 4—5 billion USD2000 annually in the period 2025—30.

The quantitative evaluations of the direct economic benefits of cooperation among CAC countries reported in this paper are based on a lot of assumptions about their present energy supply and demand systems. If in the future the countries will collect more and more detailed primary statistical data and make them more reliable through better and more detailed energy balances, less assumptions will be necessary, better model will be built and more reliable evaluations will be obtained.

[20] The actual economic benefits for the countries would be much higher than the direct revenues from oil and gas export and should be estimated with the use of appropriate consumer's and producer's multipliers.

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