## The TIMES- Central Asian Caspian Model (TIMES-CAC)

1. **Short overview (150-250 words)**

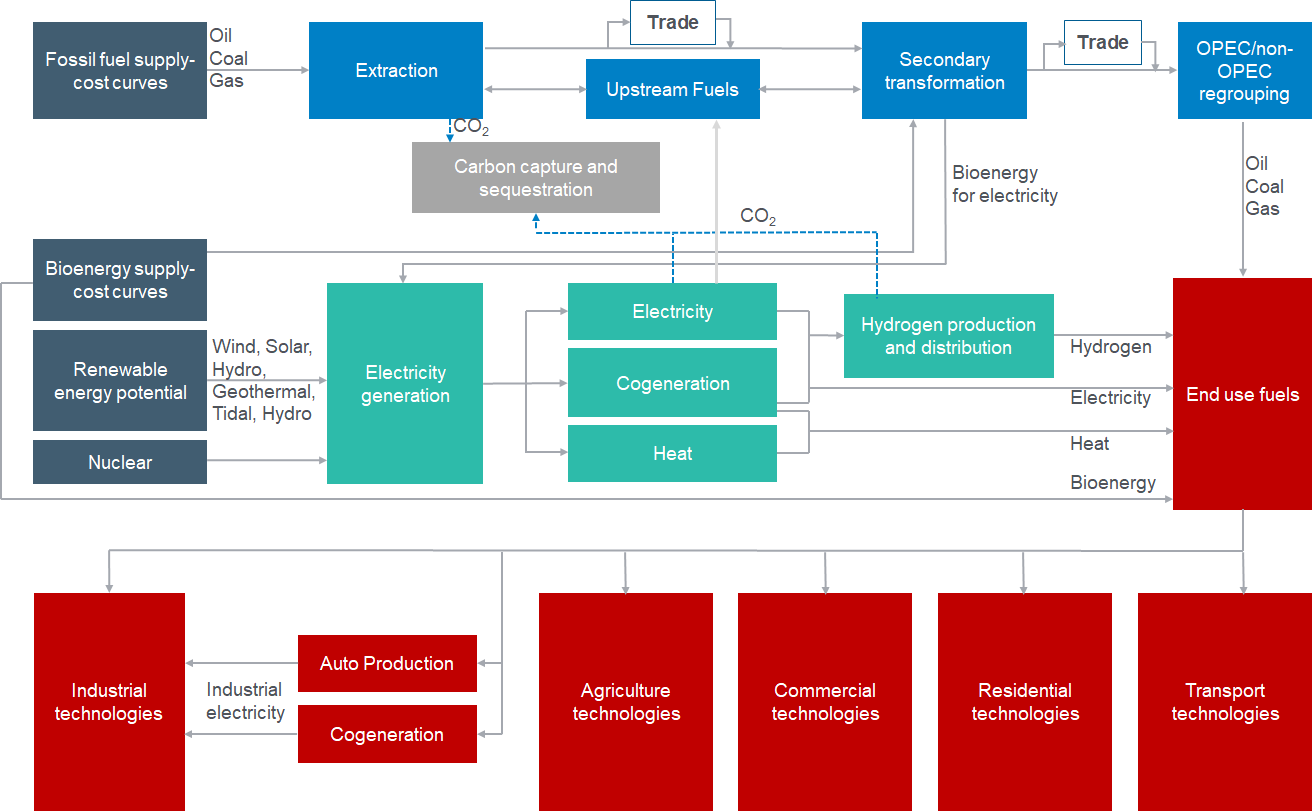
TIMES is a modelling platform for local, national or multi-regional energy systems, which provides a technology-rich basis for estimating how energy system operations will evolve over a long term, multiple period time horizon (Loulou and Labriet, 2007). These energy system operations include the extraction of primary energy such as fossil fuels, the conversion of this primary energy into useful forms (such as electricity, hydrogen, solid heating fuels and liquid transport fuels), and the use of these fuels in a range of energy service applications (vehicular transport, building heating and cooling, and the powering of industrial manufacturing plants). In multi-region versions of the model, the trade of fuels between regions is also estimated. The TIMES framework is usually applied to the analysis of the entire energy sector, but may also be applied to the detailed study of single sectors (e.g. the electricity and district heat sector). The framework can also be used to simulate the mitigation of non-CO2 greenhouse gases, including methane (CH4) and nitrous oxide (N2O).

The integrated bottom-up partial-equilibrium energy system model of the Central Asian Caspian Area, titled TIMES-CAC, assembles the four separate but structurally-consistent single-region TIMES country models of Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan[[1]](#footnote-1) by interconnecting them through the representation of energy flows and emission permits exchanges. The multiregional model is thought and designed as a comprehensive framework, able to explore national and/or supra-national forces, in a long time horizon (until 2050), with the aim to test the effects of long-term energy export strategies on the energy system of the Central Asian Caspian Countries and analyse trade-off curves between “risk” indicators and key KPIs, such as the system cost, the quantities exported and the corresponding revenues, the emission reduction ambitions.

1. **Key features of the TIMES-CAC model**

*2.1 Energy sectoral detail*

The key-components of the TIMES-CAC national tools are the technologies for the production of primary and secondary commodities (mining & extractions processes, power plants, refineries, etc.) together with the most representative appliances and devices of the demand sectors (boilers, lighting bulbs, road vehicles, etc.). The energy system development of each model region is driven by a set of demands for energy services in all sectors: agriculture, residential, commercial, industry, and transportation.



***Figure 1 – Representation of the TIMES-CAC energy system for each region (equivalent to the TIAM model)***

Source: Authors, based on the original design of Loulou and Labriet (2007)

*2.2 Geographic coverage*

In its default version, the TIMES-CAC model covers four explicit regions (countries). A number of export routes (towards 3 key areas of energy transit/consumption, namely Russia, Europe, China, which all well-represented in the *Paris Reinforce* consortium) are also simulated, as shown in following figures. (Structure and data as included in the current version of the model).

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|  |  |

***Figure 2 - Regional representation in TIMES-CAC, connection with the rest of the world (RoW), and key data***

Source: Authors, elaborations for internal reports and conferences. Oil trade routes (red arrows) and gas trades routes (yellow arrows). A Southern route “to India” (through Afghanistan) can also be analysed.

*2.3 Multi-year time periods*

The time horizon over which TIMES-CAC simulates the evolution of the energy system is divided into a user-chosen number of time-periods. In its default (current) version, model runs from 2011 (base year) to the medium-to-long term through 6 periods (the representative years of which are: 2011, 2013, 2020, 2030, 2040, 2050). All years in a given period are considered identical. For all quantities such as installed technology levels, power plant capacities and energy and emissions flows, any annual input quantity (e.g. coal used in a power plant per year) or output quantity (e.g. electricity generated from the coal plant per year) related to a given time period applies identically to each of the years in that period.

In the framework of the project, model can be further calibrated to different references years and run different horizons/organization of periods (if needed/helpful).

*2.4 Intra-year time periods (time slices)*

In addition to the multi-year time periods described above, in TIMES-CAC there are time divisions ***within*** a year, called “time slices”, which may be deﬁned by the user, so as to capture different weather, consumer behaviours, and energy demand conditions at different times of the year. There are currently 9 time-slices representing summer daytime, summer night time, and a peak moment in summer, winter daytime, winter night time, and a peak moment in winter, and an intermediate season day time and night time and peak moment in the intermediate season.

Time-slices are especially important whenever the mode and cost of production of an energy carrier at different times of the year are signiﬁcantly different (Loulou and Labriet, 2007). This is the case for instance when the demand for an electricity ﬂuctuates across the year and a variety of technologies may be chosen for its production at given times of the year (such as wind power when wind resources are high, and solar photovoltaics when there is a high availability of solar radiation. In such cases, the matching of supply and demand requires that the activities of the technologies producing and consuming the electricity be tracked – and matched - in each time slice.

1. **Climate module & emissions granularity**

The model tracks the three main sources of greenhouse gases - carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20). A special module of the TIMES-CAC can be enabled to let other two countries of the Central-Asian region (virtually modelled), to participate in the GHG emission reduction effort (through a virtual market trading scheme extended to 4+2 regions of the area).

1. **Socioeconomic dimensions**

The TIMES-CAC model requires inputs concerning the degree to which energy service demands, as well as demand for other goods and services which result in greenhouse gas emissions (such as agricultural demand), will grow over the course of next decades in the different countries. It does this by using various socio-economic inputs, as described in the following table (current default values) and sections. Data will be revised and updated before running the model under the *Paris Reinforce* project.

***Table 1 - Key socio economic inputs in TIMES-CAC***

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Indicator** | **Values** | **In 2009** | **Growth index (2009=100)** | | | | |  |
|  |  |  |  | **2020** | **2025** | | | **2030** | **2050** |
| AZJ | Population | Million | 8.8 | 118 | | 124 | 130 | | \*1.5 wrt the BY |
| GDP per capita (&) | US$’2000ppp | 8702 | 175 | | 217 | 251 | | Study-specific |
| Aggregate demand for energy services | Index (+) | 100 | 199 | | 265 | 328 | | Study-specific |
| KZK | Population | Million | 15.9 | 118 | | 124 | 130 | | \*1.5 wrt the BY |
| GDP per capita (&) | US$’2000ppp | 8400 | 161 | | 196 | 238 | | Study-specific |
| Aggregate demand for energy services | Index (+) | 100 | 167 | | 209 | 264 | | Study-specific |
| TKM | Population | Million | 5.1 | 118 | | 124 | 130 | | \*1.5 wrt the BY |
| GDP per capita (&) | US$’2000ppp | 9859 | 175 | | 217 | 251 | | Study-specific |
| Aggregate demand for energy services | Index (+) | 100 | 179 | | 226 | 269 | | Study-specific |
| UZB | Population | Million | 27.8 | 118 | | 124 | 130 | | \*1.5 wrt the BY |
| GDP per capita (&) | US$’2000ppp | 2395 | 175 | | 217 | 251 | | Study-specific |
| Aggregate demand for energy services | Index (+) | 100 | 185 | | 238 | 283 | | Study-specific |
| CAC-4R | Population | Million | 57.6 | 118 | | 124 | 130 | | \*1.5 wrt the BY |
| GDP per capita (&) | US$’2000ppp | 5678 | 170 | | 208 | 246 | | Study-specific |
| Aggregate demand for energy services | Index (+) | 100 | 178 | | 226 | 278 | | Study-specific |

*4.1 Economic growth*

As almost for all the most important energy-producing countries, even the CAC countries are highly dependent on energy exports, and this dependence results in a very large share of the energy sector to the GDP and fundamental (critical) contributions to the State budgets. Economic growths are based on national specific projections for the medium-term, and on hypotheses (study- and scenario-specific) for the longer horizon. In general terms, the analysed storylines always assume a (quite fast) growth in domestic GDPs for all the cases and countries, that in a “base case” is equivalent to a an economic trend of around +4.5% (in terms of GDP, in average, to 2050).

But due to the above mentioned characteristics, economic growths in the CAC area (by country) should be always properly assess and considered within a self-consistent (energy related) storyline, in order to keep a certain degree of robustness of the scenario and of the projections.

*4.1 Population growth*

Population growths are also based on national (local) specific information in the medium term and on assumptions in the longer horizon (mainly inherited by a specific analysis for Kazakhstan), that result in a population growth rate of +1.2%, in average, in the long-term (2050), for the multiregional area. It is worth noting that, according to some local experts, the international analyses often “underestimate” the population growth rates of the area, due to the incorrect comparison with Russia (and the FSU) and with the Russian ethnic groups (lower birth rates).

It should be also noted that the TIMES-CAC model can be adjusted to use other socio-economic growth projections aside from the default.

*4.3 Sectoral growth*

The growth in the industrial, agricultural and retail business sectors in each region is partially derived from the national’s overall GDP growth, with each sector’s share of total GDP changing over time, and from the expected/planned production levels, constructions (eg square meters for services), and development of certain activities. Growth of residential households is derived from population growth and assumptions on average household size in each region.

Growth in each of these sectors drives energy demand as described in the next sub-section.

*4.4 Energy demand drivers and demand elasticities*

The economic, population and sectoral growths (eg physical production of industrial activities) are used as specific drivers for the growth in energy demands.

Once the drivers for the different energy demands represented by TIMES-CAC model are selected, allocated and quantified, the construction of the reference demand scenario requires computing a set of energy service demands over the horizon. This can be done by choosing elasticities of demands to their respective drivers, in each region, using the following general formula:

Demand = Driver Elasticity

So for example the number of billion vehicle km travelled by automobiles, bvkm, grows by a factor which is the growth in the GDP per capita in a region to the power of a pre-defined elasticity:

bvkm = (GDP/capita)Elasticity

TIMES-CAC has the capability of estimating the price-based response of these energy service demands to the changing conditions of scenarios in which mitigation occurs. For example, if the cost of energy increases as fossil fuels are replaced by renewables, then the demand for energy services would decrease. To do this, TIMES-CAC can make use of another set of inputs, namely the price elasticities of the demands for each energy service considered. In the default version of the model this option is disabled so that energy service demands are assumed to be inelastic (some modelling adjustments to simulate the improvement of living conditions in the residential sector are taken into account).

1. **Calibration of the model**

The TIMES-CAC model is calibrated for the initial period (currently 2011) using a combination of IEA world energy statistics for the year 2011 and country-specific information, with the projections for the key energy-related investments and stocks (eg installed technology capacity) further calibrated until 2013-2015. The current intention is that the version of TIMES-CAC to be used in *Paris Reinforce* will have an updated energy statistics calibration (the most useful combination among the key international and local sources) to the most recent years. The main variables to be calibrated are: the capacities/stocks and operating levels of all technologies, the extracted, exported, imported, produced, and consumed quantities for all energy carriers, and the introduction/representation of recent (new) policy- and target-related elements (if any).

1. **Mitigation / adaptation measures and technologies**

TIMES-CAC is a technology-rich model that represents most major fossil fuel and low-carbon technologies that are envisaged to be available (for those systems) for at least the first half of the 21st century. By simulating the substitution of low-carbon for high-carbon technologies in response to their relative costs, as well as emissions constraints and/or carbon prices, the model simulates mitigation. The principal energy sector CO2 (and non- CO2) mitigation options are shown in the following table (*in black, the options available in the current version of the model, in grey the ones that can be added*). Data will be revised and updated in the framework of the *Paris Reinforce* project, and in accordance with the international database and feedback of local experts.

***Table 2 - Main GHGenergy system mitigation options in TIMES-CAC***

|  |  |
| --- | --- |
| **Upstream** | |
| ***Synthetic fuel production*** | ***Hydrogen production*** |
| Coal to gas without CCS  Coal to liquids without CCS  Biomass to gas without CCS  *Coal to gas with CCS*  *Coal to liquids with CCS*  *Gas to liquids with CCS*  *Biomass to liquids (with and without CCS)* | Electrolysis  Coal to hydrogen with CCS  *Gas to hydrogen with CCS*  *Biomass to hydrogen with CCS* |
| **Electricity and heat** | |
| ***Electricity generation*** | ***Heat generation*** |
| Coal with CCS  Gas with CCS  *Nuclear (fission and fusion)*  Hydro  Biomass (with and without CCS)  Geothermal  Solar PV  Solar CSP  Wind (onshore and offshore)  *Marine* | *Coal with CCS*  *Gas with CCS*  *Oil with CCS*  *Geothermal*  Biomass  *Biomass with CCS* |
| **Transport** | |
| ***Road*** | ***Rail*** |
| Gas (LNG / CNG) vehicles  Hybrid electric vehicles  Fully electric vehicles  Hydrogen fuel cell vehicles  Biofuels in fuel mix  Efficiency | Electric  *Hydrogen*  *Efficiency* |
| ***Air*** | ***Marine*** |
| Biofuels in fuel mix  *Hydrogen planes*  *Efficiency* | *Gas*  *Hydrogen*  *Biofuels*  *Efficiency* |
| **Buildings** | |
| ***Heating*** | ***Lighting*** |
| Gas replacing coal / oil  Biofuels  Electricity  Hydrogen  Efficiency | Efficiency |
| ***Appliances*** | ***Cooling*** |
| Efficiency | Electricity  Efficiency |
| **Industry** | |
| ***Process heat*** | ***Machine drives*** |
| Gas replacing oil / coal  Biomass  Hydrogen  Electricity | Gas replacing oil / coal  Electricity |
| ***Steam*** | ***CHP*** |
| Gas replacing oil / coal  Electricity | Gas replacing oil / coal  Biomass |
| ***CCS*** | ***Other*** |
| CCS in iron and steel (for auto-producers only)  CCS in cement (for auto-producers only)  CCS in chemicals (for auto-producers only) |  |
| **Agriculture** | |
| ***Energy*** | ***Other*** |
| Biomass  Electricity |  |
| **Non-CO2** | |
| Enteric fermentation + Digester + Cogeneration (Agriculture) | Flare gas recovery + on site use |
| Waste water processing with recovery + cogeneration (Industry) | Flare gas recovery + compression + distribution |

1. **Economic rationale and model solution**

According to its analytical paradigm, the TIMES-CAC model computes a dynamic inter-temporal partial equilibrium for the (multi-) regional energy and emission markets, based on the maximization of total surplus defined as the sum of surplus of the suppliers and consumers. In other words, it is assumed that the multi-regional system evolves, while maintaining intra-temporal and inter-temporal partial economic equilibrium, and always occupies the technical possibility frontier. The process of solving the model determines the optimal mix of technologies (capacity and activity) and fuels at each period, the associated emissions, the mining and “trading activities”, the quantity and prices of all commodities, all in time series from the base year to the time horizon of the model.

The model was mainly developed and used to assess the dynamics of the national energy system of the area in cooperative and non-cooperative manner, when energy export levels are determined by the willingness to pay of the different “importers/customers”[[2]](#footnote-2).

The model responds to economic incentives (such as revenues from the exports) by optimising the domestic energy system (supply and demand of each energy form), the energy exchanges within the multiregional system (CAC area), and with the external markets, in an “integrated” manner. A “discount” factor of 5% per year is used to value the costs of the energy system at different time points in the future. In other words, a cost of $100 one year in the future would be equated to a cost of $95 today. This discount factor can be changed. Implicit discount rates are also used at sectoral level.

The TIMES-CAC model is solved using a mixed-integer-linear programming (MILP) option of the CPLEX solver, through which the most suitable “size” (capacity of the process) of each cross-country infrastructure is selected (included in the optimal solution).

1. **Key parameters**

The TIMES-CAC model is “by paradigm” a technology rich tool where techno-economic information are assigned to each process (existing and future) of the system, and therefore many data/parameters can be extracted and reported.

Based on the geopolitical and strategic role of the CAC area in the international “energy” context, and on its specific technical and market characteristics which affect the local energy and climate plans, the following key information are selected as the “most important” parameters to monitor, discuss and evaluate in the framework of the *Paris Reinforce* project for a successful integration of this model with the other tools and analyses:

* Fossil fuels proven/possible reserves (mainly oil and gas) and expected production rates (P/R).
* Quantities and (or) prices of trades (mainly for oil and gas), by area of import.
* Information about under construction/planned/possible energy projects/infrastructures.
* Burden/contribution of the countries/area to global climate targets (based on previous experiences, this is particularly relevant with respect to the gas allocation: domestic use VS export), and national emission reduction goals.
* Energy efficiency improvements costs/limits (from the supply side to the demand side).
* Renewable energy and CCS costs/potentials.
* Others (tbd).
* Locals-specific priorities, targets, plans.

Parameters can be revised and updated in the framework of the *Paris Reinforce* project, following the feedback of local experts (stakeholder engagement), the comparative assessment with other modelling experiences, and the discussion with the partners (modellers).

**9. Policy questions and SDGs**

*9.1 Key policies that can be addressed*

As for all the TIMES-based models, the TIMES-CAC predominantly works by specifying either a carbon price (imposed as a tax) or a carbon emissions constraint in each region that it represents, or alternatively all regions simultaneously. For example the following further policies can be implemented:

* Minimum / maximum capacity factors on fossil fuel power generation plants (e.g. to simulate minimum or maximum desired levels of operation);
* Subsidies on particular technologies (through adjusting their costs or the explicit assignment of incentives);
* Constraints on the availability of particular technologies (e.g. “no nuclear”, variable renewables accounting for no more than 50% of electricity generation);
* Constraints on the growth rates of particular technologies (e.g. carbon capture and storage power generation capacity cannot grow at more than 20% per year)
* Inter-regional emissions trading (or no trading);

More in particular, the TIMES-CAC is capable to explore the direct economic advantage of cooperation policies in the energy and climate change mitigation sectors for the represented countries. The following cooperation policies in the area can be directly modelled:

* exploitation of Caspian oil and natural gas resources;
* investment in the construction of cross-national new pipelines;
* maintenance of free exchange in the energy sector across the region; and
* creation of a joint CO2 emission permit system in the area.

Furthermore, the structure of the TIMES-CAC model allows to fully include the concept of “energy security” in the analysis (from the perspective of energy exporters), and to test the effects of long-term energy export strategies in the Central Asian Caspian (CAC) region by exploring the *trade-offs* between a “risk” indicator and some key variables of the energy system such as the total cost, the quantities exported and the corresponding revenues, the climate targets of the region. Furthermore, (export) risk reduction goals can be combined with securing a minimum level of revenues from the hydrocarbon exports goals, with the aim to quantitatively evaluate the response of the energy sector and its sensitivity to different export strategies.

Table below provides additional information about the capability of the model to represent policies and measures per each key energy&climate dimensions.

***Table 3 - Capability of the TIMES-CAC to address PaMs***

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| --- | --- |
| **PaMs (by dimension)[[3]](#footnote-3)** | **TIMES-CAC** |
| Decarbonisation | ***High*** capability (several mitigation options, regulatory and economic measures, etc.) |
| Energy Efficiency | ***High*** capability (several energy efficiency options, regulatory and economic measures, etc.) |
| Energy Security | ***High*** capability (key focus of the TIMES-CAC, risk and diversification targets) |
| Internal energy markets | ***Medium*** capability (gasification of the systems, electrifications, partial/complete phase-out of fuel subsidies, etc.) |
| Research, Innovation and competitiveness | ***Low-Medium*** capability (implicit and/or ex-post) |

*9.2 Implications for other SDGs*

Apart from the above mentioned dimensions, a number of other SDGs can be taken into consideration and investigated making use of the TIMES-CAC model, as shown below.

***Table 4 - Capability of the TIMES-CAC consider/assess other SDGs***

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| --- | --- |
| **SDGs** | **TIMES-CAC** |
| §1. No Poverty (e.g., intra-country distributional impact by income level) | ***Partial***. Trade-offs between energy poverty reduction (residential) measures VS energy consumptions can be partially explored. |
| §3. Health (e.g., air-pollution related mortality) | ***Implicitly***. Measures to tackle the use of solid fuels in buildings (not negligible fractions in the CAC area, and direct cause of pollution-related mortality) can be included. |
| §7. Affordable and clean energy (e.g., traditional biomass use, %renewable energy) | ***Full***. Cost-effectiveness of RES within a specific storyline. |
| §8. Decent work & economic growth (e.g., impact on GDPpc, jobs) | ***Partial***. Energy export revenues can be tracked and analysed to evaluate the corresponding relevance/impact on the State budget (eg capability to fund RES, etc.) and on the domestic macroeconomic indicators. |
| §15: Life on land (e.g., land use for forests, rate of land use change) | ***Limited/Simplified***. Afforestation measures can be taken into account; RES potential/exploitation and investment decisions (eg energy infrastructures) can be subject to land-specific constraints (natural and regulatory). |

**10. Recent publications using the TIMES-CAC model (or using national-specific analysis based on the utilization of single-regions tools inherited by the TIMES-CAC)**

|  |  |
| --- | --- |
| **Paper** | **Topic** |
| A. Kerimray, B. Suleimenov, R. De Miglio, L. Rojas-Solórzano, B. P. Ó Gallachóir (2018).  Limiting Global Warming to Well Below 2 °C Energy System Modelling and Policy Development. Springer. DOI: 10.1007/978-3-319-74424-7 | *Long-Term Climate Change Mitigation in Kazakhstan in a Post Paris Agreement Context*.  Under the Paris Agreement, Kazakhstan’s nationally determined contribution (NDC) target is to reduce its greenhouse gas emissions (GHG) by between 15 and 25% by 2030 compared with 1990 levels. Kazakhstan’s energy system is highly carbon intensive and GHG emissions continue to steadily grow, indicating insufficient progress towards achieving the NDC emissions reductions announced under the Paris Agreement. This chapter presents modelling analysis that assesses a least-cost long term (2050) pathway towards achieving these NDC targets. The results demonstrate how ambitious a 25% GHG emissions reduction pathway is compared with the current energy policies and mitigation actions. Such a reduction requires an almost full phase-out of coal consumption in power generation by 2050. |
| A. Bakdolotov, R. De Miglio, Y. Akhmetbekov, K. Baigarin (2017).  Heliyon, Vol3 Issue4. DOI: https://doi.org/10.1016/j.heliyon.2017.e00283 | *Techno-economic modelling to strategize energy exports in the Central Asian Caspian region*.  This paper studies the concept of energy security from export-oriented countries’ point of view. It aims to test the effects of long-term energy export strategies in the Central Asian Caspian (CAC) region, by exploring the trade-offs between a “risk” indicator and some key variables of the energy system such as the total cost, the quantities exported, and the corresponding revenues. Risk reduction goals are combined with securing a minimum level of revenues from the hydrocarbon exports goals. It is also attempted to provide a definition and a quantification of a risk indicator on the basis of four components. |
| Aiymgul Kerimray, Rocco De Miglio, GianCarlo Tosato (2015)  Informing Energy and Climate Policies Using Energy Systems Models, Springer International Publishing (DOI 10.1007/978-3-319-16540-0) | *Improving Efficiency in Kazakhstan’s Energy System*  There are various reasons for inefficiencies in Kazakhstan’s energy system: administrative and economic (statistical double counting of energy flows, above normative losses and low profitability), geographic (the extremely continental climate and low population density) and technical considerations (high share of coal in generation mix, high wear on main and auxiliary equipment in energy intensive sectors, high wear on electric lines, dilapidation of housing stock, and an absence of control systems for energy savings) all contribute to the high energy intensity. This study explores energy efficiency potential by analyzing the evolution of the Kazakh energy system. All the technical inefficiencies have been taken into consideration through the explicit representation of existing inefficient technologies/chains in a TIMES-based model. Under the assumptions of a market-oriented development of the economic system, even without specific policies (Business as Usual), the model suggests significant energy efficiency improvement: 22 Mtoe (million tons of oil equivalent) by 2030 and a 40 % reduction in energy intensity of GDP by 2030. |
| Rocco De Miglio, Yerbol Akhmetbekov, Kanat Baigarin, Aidyn Bakdolotov, GianCarlo Tosato (2014)  Energy Strategy Reviews. [doi.org/10.1016/j.esr.2014.09.002](https://doi.org/10.1016/j.esr.2014.09.002) | *Cooperation benefits of Caspian countries in their energy sector development*.  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](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/domestic-energy) efficiencies and increase their export of fossil energy commodities. 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](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/climate-change-mitigation). |

**Key References**

Loulou, R., Labriet, M., 2007. ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. Comput. Manag. Sci. 5, 7–40. https://doi.org/10.1007/s10287-007-0046-z

International Energy Agency, Beyond 2020, Extended and Summary Energy Balances of Non OECD countries, (2012). http://www.iea.org/statistics/.

Energy Information Administration, Overview of oil and natural gas in the Caspian Sea region, (2013) 1–25. <http://www.eia.gov/countries/analysisbriefs/Caspian_Sea/caspian_sea.pdf>.

Energy Charter, 2015, International Energy Security: Common Concept for Energy Producing, Consuming and Transit Countries.

1. Two extra “implicit” regions, Kyrgyzstan and Tajikistan, can be enabled to further explore electricity synergies and emission reduction cooperative strategies. In its default version, the model is built upon 4 regions only and it is named TIMES-CAC-4R. [↑](#footnote-ref-1)
2. Model can currently run in two modes: with exogenously defined export levels per each direction of export, or with endogenously defined export levels through the most profitable route and destination. A risk-specific analysis can also be enabled to strategize the export of the region. [↑](#footnote-ref-2)
3. According to the new rules on governance of the EU energy union [↑](#footnote-ref-3)