Bottom-up modeling of residential sector decarbonisation scenarios

Intermediate results

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Introduction
Coal use by households

- Kazakhstan takes 4th place in the world with its per capita residential coal consumption.
- 40% of households in Kazakhstan use coal (mainly in rural areas).
- Mostly burned in the hand-made inefficient stoves.

- Large territory, low population density
- High demand for heating
    - Heating-Degree-Days/year 4000-7000 $°C$

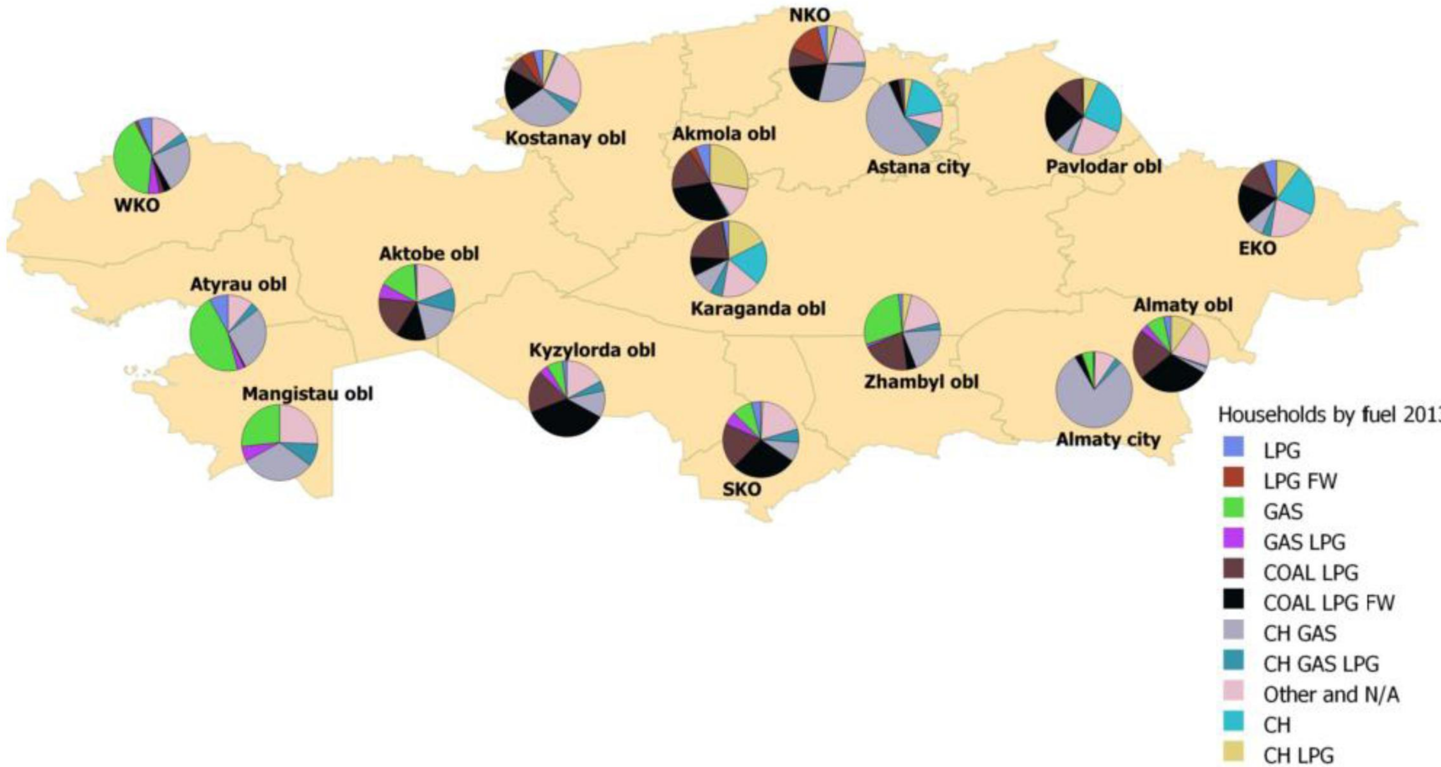
HEALTH EFFECTS (WHO, 2014)
- Lung cancer
- Respiratory effects
- Developmental and reproductive effects
- Acute CO poisoning and other


Solid fuel-fired stove in Kazakhstan (Taraz)

Kerimray A., Rojas-Solórzano L., Mehdi Amouei Torkmahalleh , Ó Gallachóir, B.P. Households Coal Use for Heating: Patterns, Implications and Lessons Learned. *Energy for Sustainable Development*.

Introduction

Households survey (12000)



- The highest number of households (2,636) use **central heating and network gas**, mainly in urban areas.
- The second most popular combination is **coal, LPG and firewood (FW)**, used mainly by rural households having no access to gas or district heating.

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Modelling tool – TIMES/MARKAL

TIMES is a technology rich, bottom-up model generator, which uses linear-programming to produce a least-cost energy system, optimized according to a number of user constraints, over medium to long-term time horizons.

OPTIMISATION PROGRAM

Min C*X	**(1)**	(1)	Is the total NPV of system cost
Subject to:		(2)	Is a larger set of technical and policy constraints
$A*X \le b$	**(2)**	(3)	Is a set of service demand satisfaction constraints
$E*X \ge dem$	**(3)**	**Solved by Linear Programming**	

The objective function is to minimize the total cost of the system:

- **Capital Costs** incurred for investing into and/or dismantling processes;
- Fixed and variable **Operation and Maintenance (O&M) Costs**;
- **Costs** incurred for exogenous imports and for domestic resource production;
- **Revenues** from exogenous exports;
- **Delivery costs** for required commodities consumed by processes;
- **Taxes and subsidies** associated with commodity flows and process activities or investments;

Loulou et al. (2005)

Decision variables

NCAP(r,v,p): new capacity addition (investment) for process : PJ/y and GW.

CAP(r,v,t,p): total installed capacity of process : PJ/y and GW. **CAPT(r,t,p):** total installed capacity of process (all vintages together).

ACT(r,v,t,p,s): activity level of process: PJ for all energy technologies.

FLOW(r,v,t,p,c,s): the quantity of commodity consumed or produced by process: PJ for all energy technologies.

SIN(r,v,t,p,c,s)/SOUT(r,v,t,p,c,s): the quantity of commodity stored or discharged by storage process.

TRADE(r,t,p,c,s,imp) and TRADE(r,t,p,c,s,exp): quantity of commodity sold (exp) or purchased (imp) through export (resp. import) process : PJ/y Bi-lateral trading, Multi-lateral trading, Exogenous trading.

D(r,t,d): demand for end-use energy service.

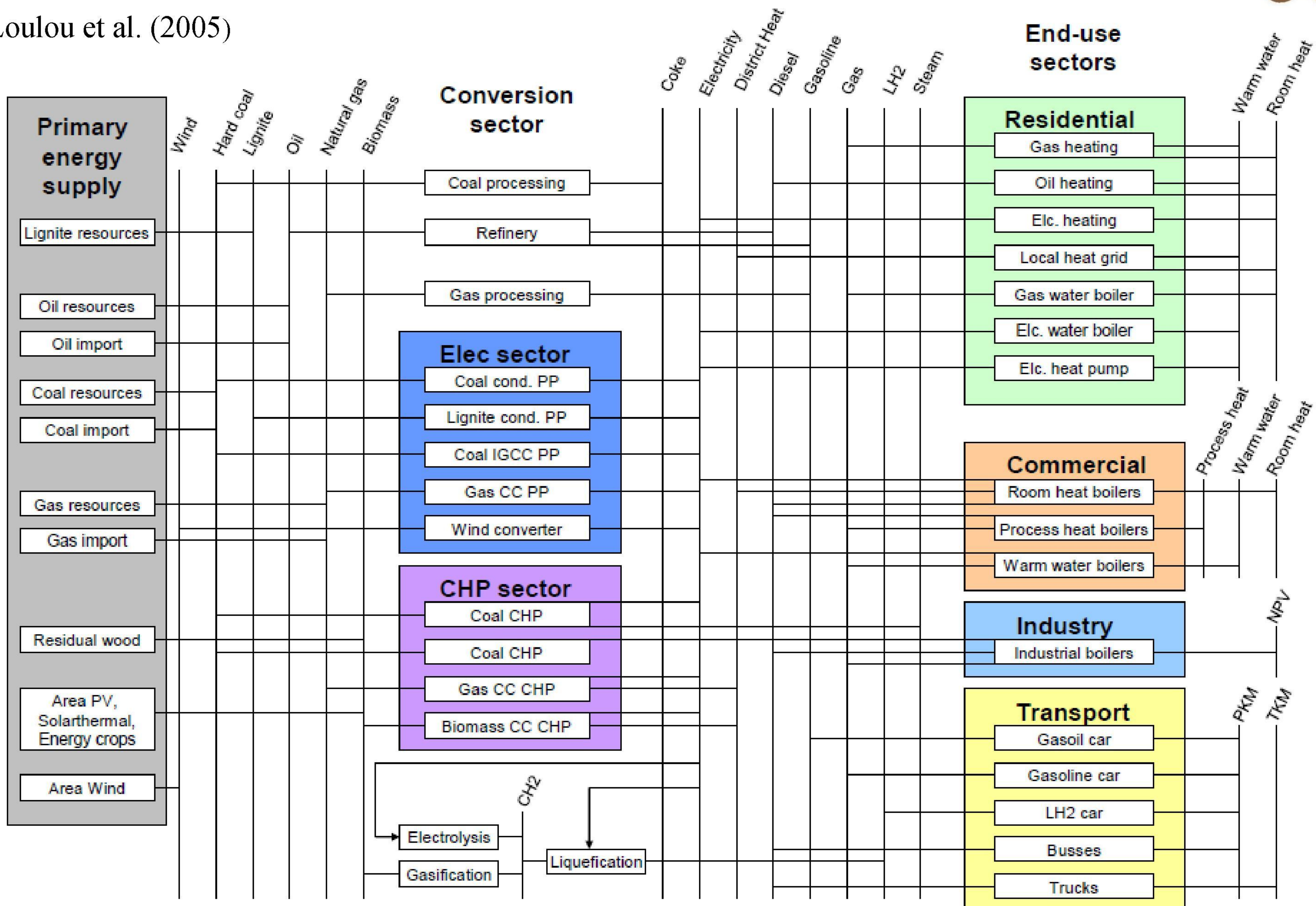
Other variables: Commodity related variables convenient for reporting purposes and/or for applying certain bounds: the total amount produced of a commodity

(**COMPRD**), or the total amount consumed of a commodity (**COMCON**).

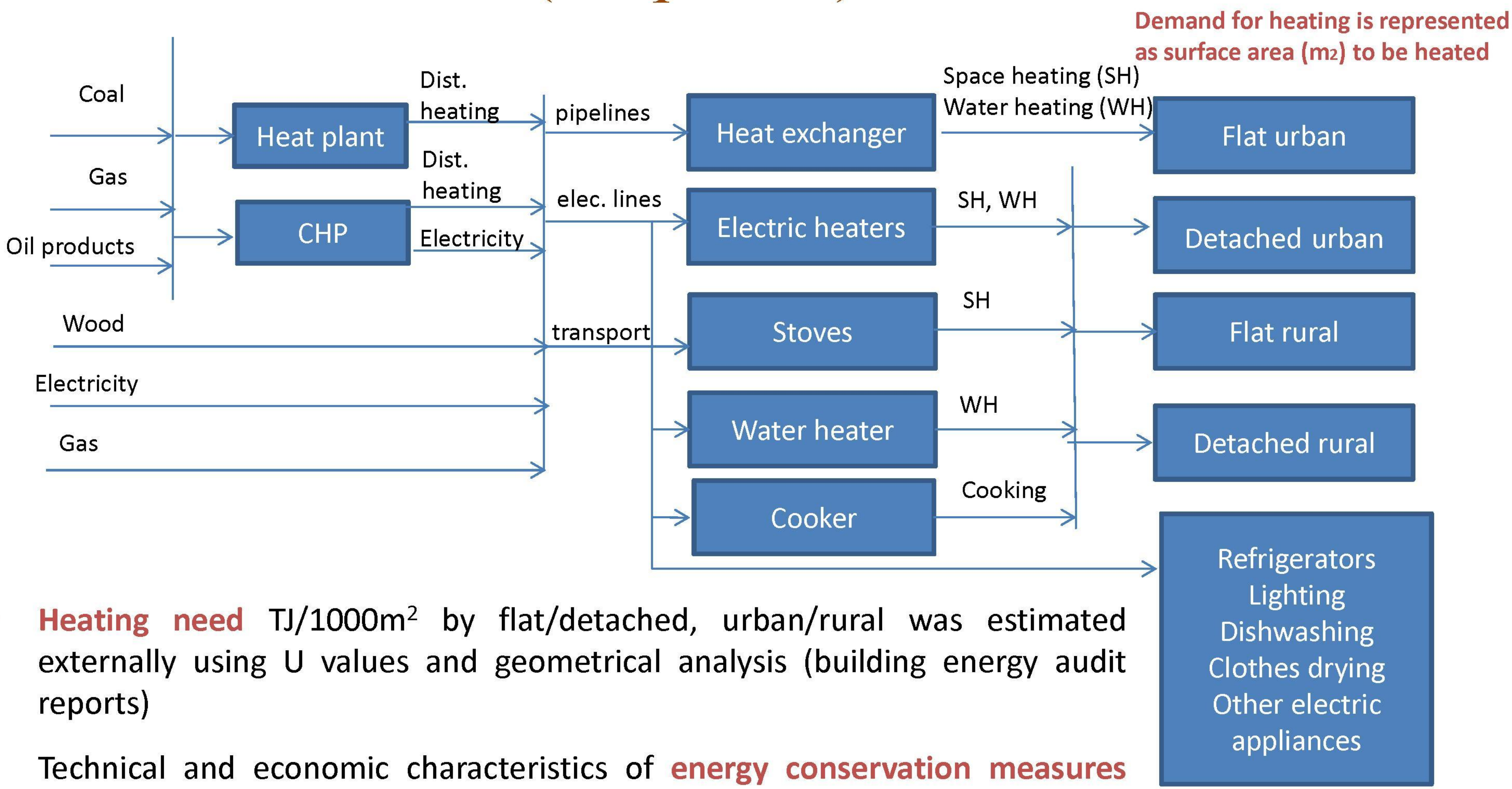
Loulou et al. (2005)

Reference energy system (simplified)

Loulou et al. (2005)



Residential sector representation in the model (simplified)

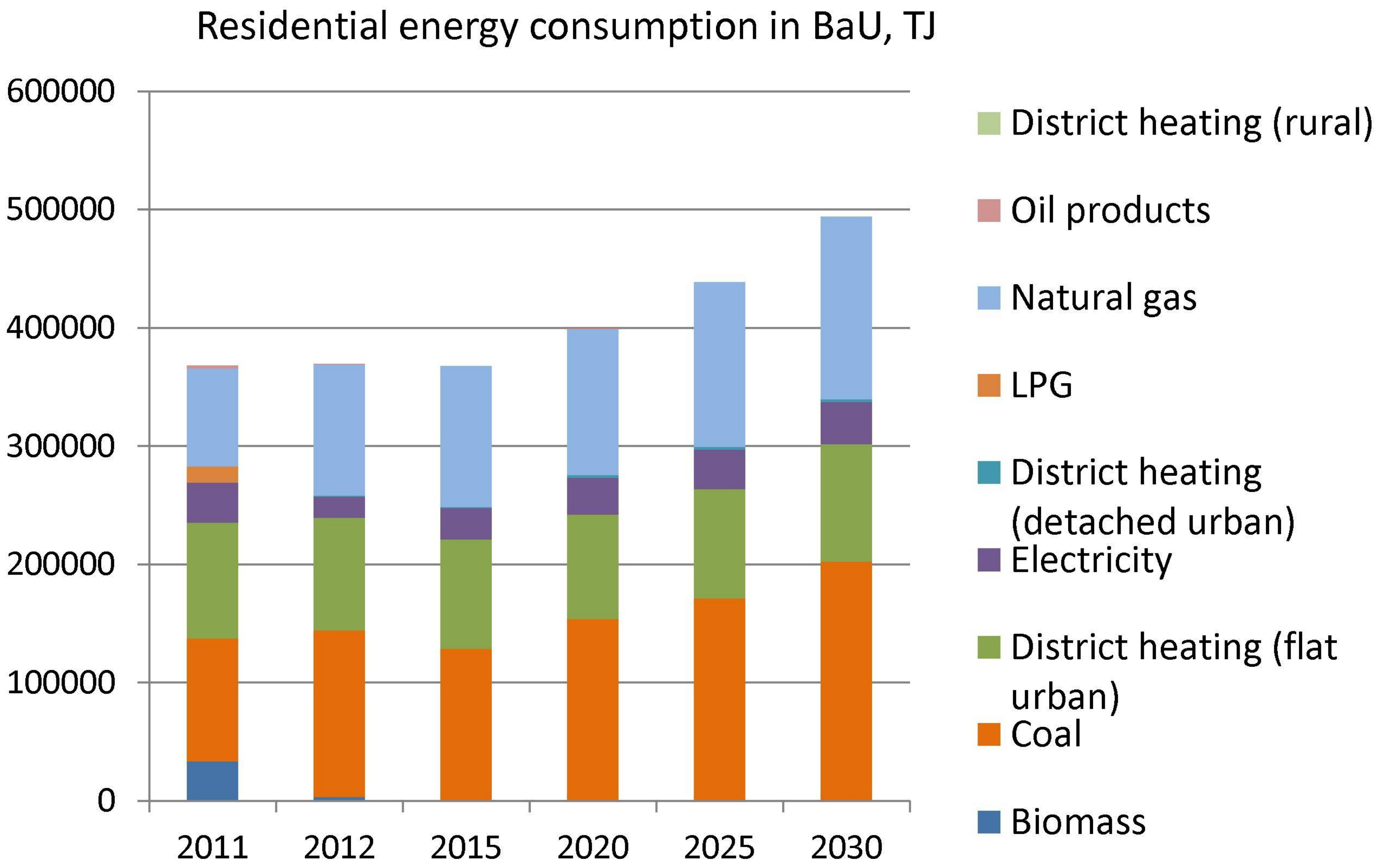


- **Heating need** TJ/1000m^2 by flat/detached, urban/rural was estimated externally using U values and geometrical analysis (building energy audit reports)
- Technical and economic characteristics of **energy conservation measures** were represented: windows replacement, wall insulation, floor insulation, replacement of doors
- **New technology options** were described: heat pumps, solar water heaters, micro-CHP, etc.

Scenarios

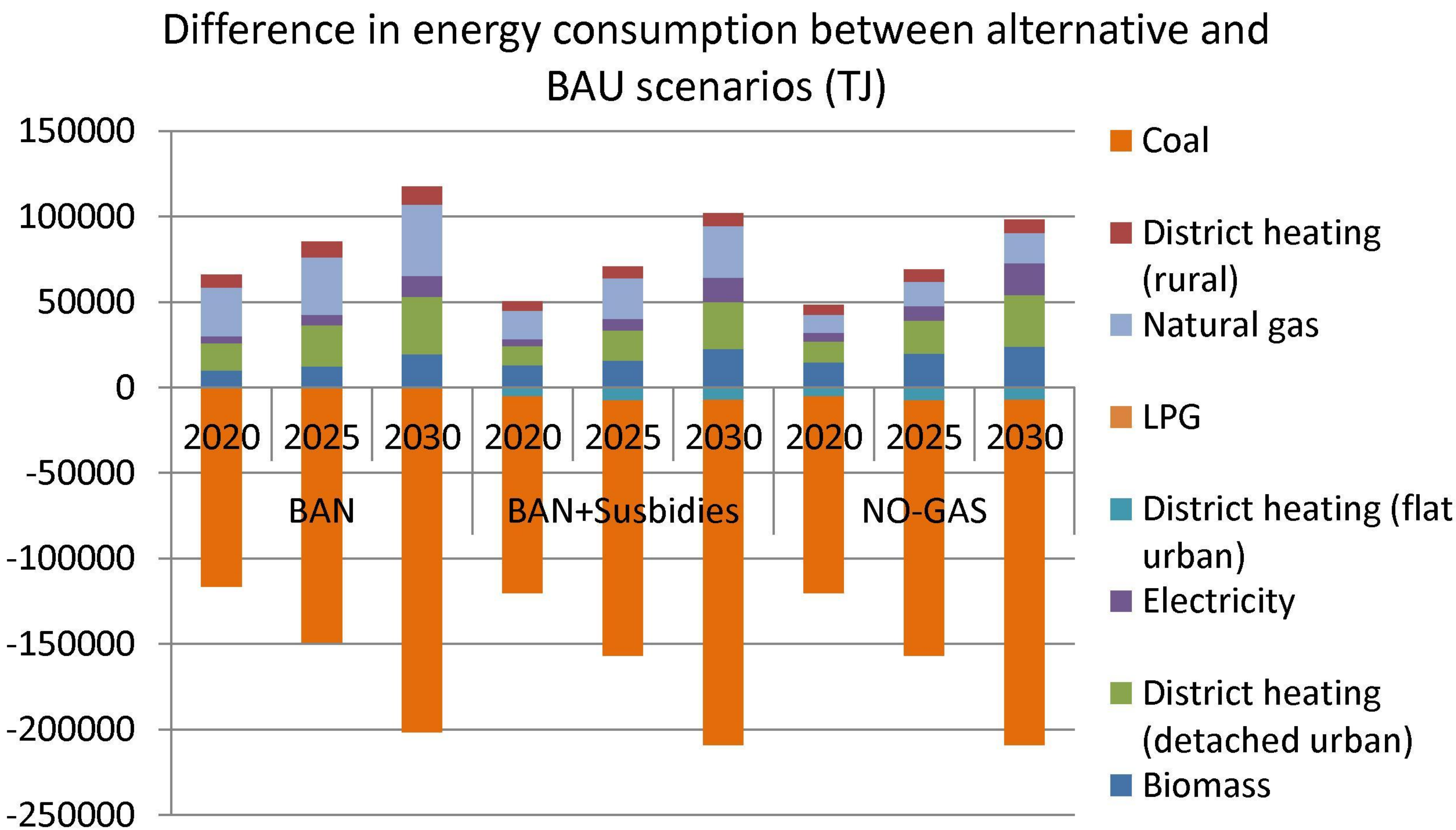
Scenario name	Definition
BaU	Least cost solution for the system. No constraints on the use of coal use, no subsidies for cleaner technologies.
BAN	Phase out of coal use in the residential sector (40% reduction of coal use by 2020% and 100% reduction by 2030 compared to the level of 2011).
BAN+ Susbidies	- Subsidies on the capacity for cleaner alternatives: micro-CHP (biogas, biomass, natural gas), heat pumps and solar space heaters in the amount of 70% of the investment cost. - Subsidies for the retrofit measures (50% of the cost): wall, roof, floor, loft, door, windows.
BAN (NO GAS)	The same as in "BAN+subsidies" scenario, but construction of new network gas pipeline to the northern and central Kazakhstan is not allowed.

Business as usual (BaU)



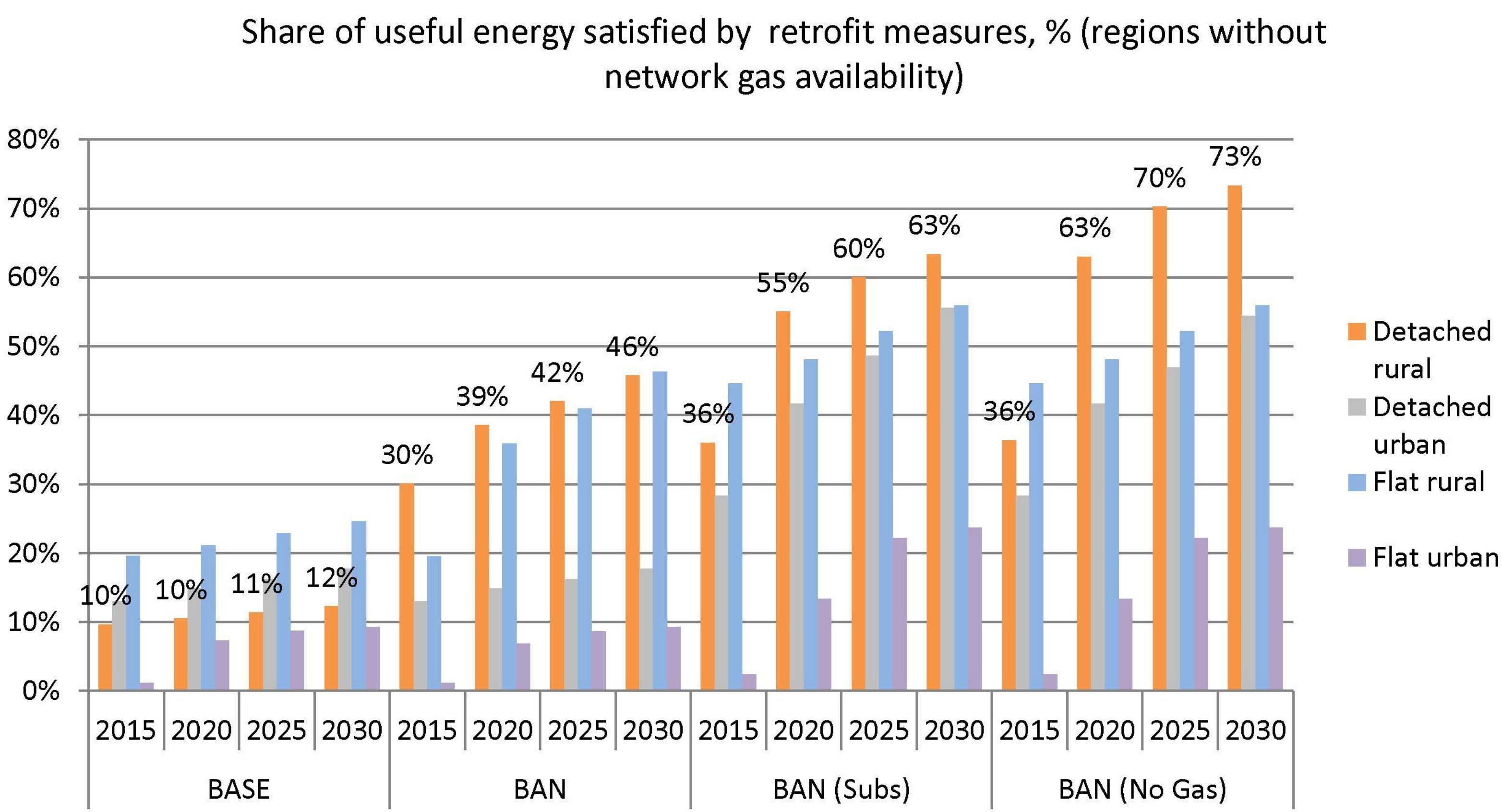
- In the Business as Usual scenario coal continue to dominate in the residential energy consumption.

Comparing BaU with alternative scenarios



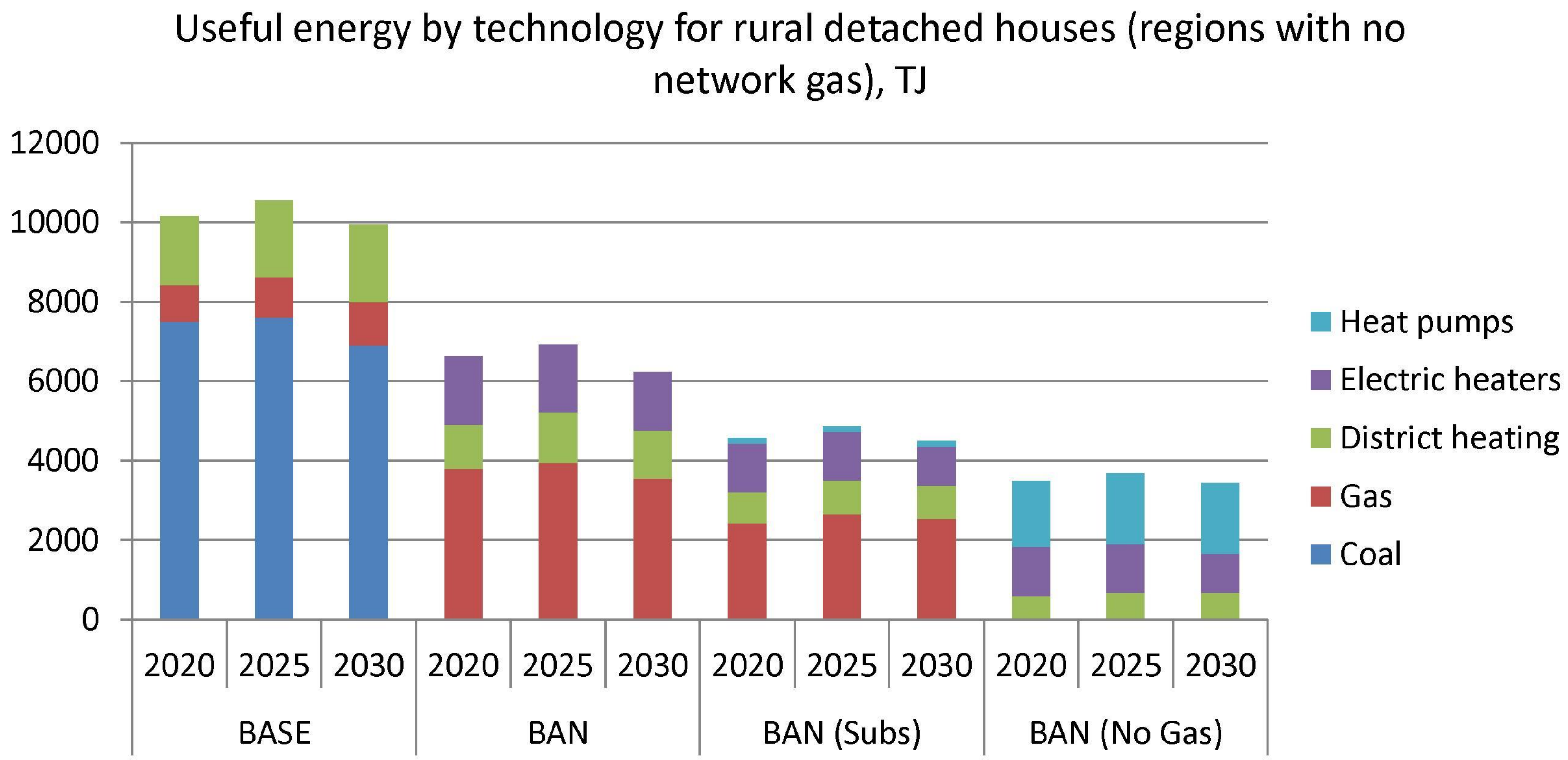
- In the scenario with coal ban, it is substituted by natural gas, district heating, biomass and electricity

Useful energy saving from retrofit measures



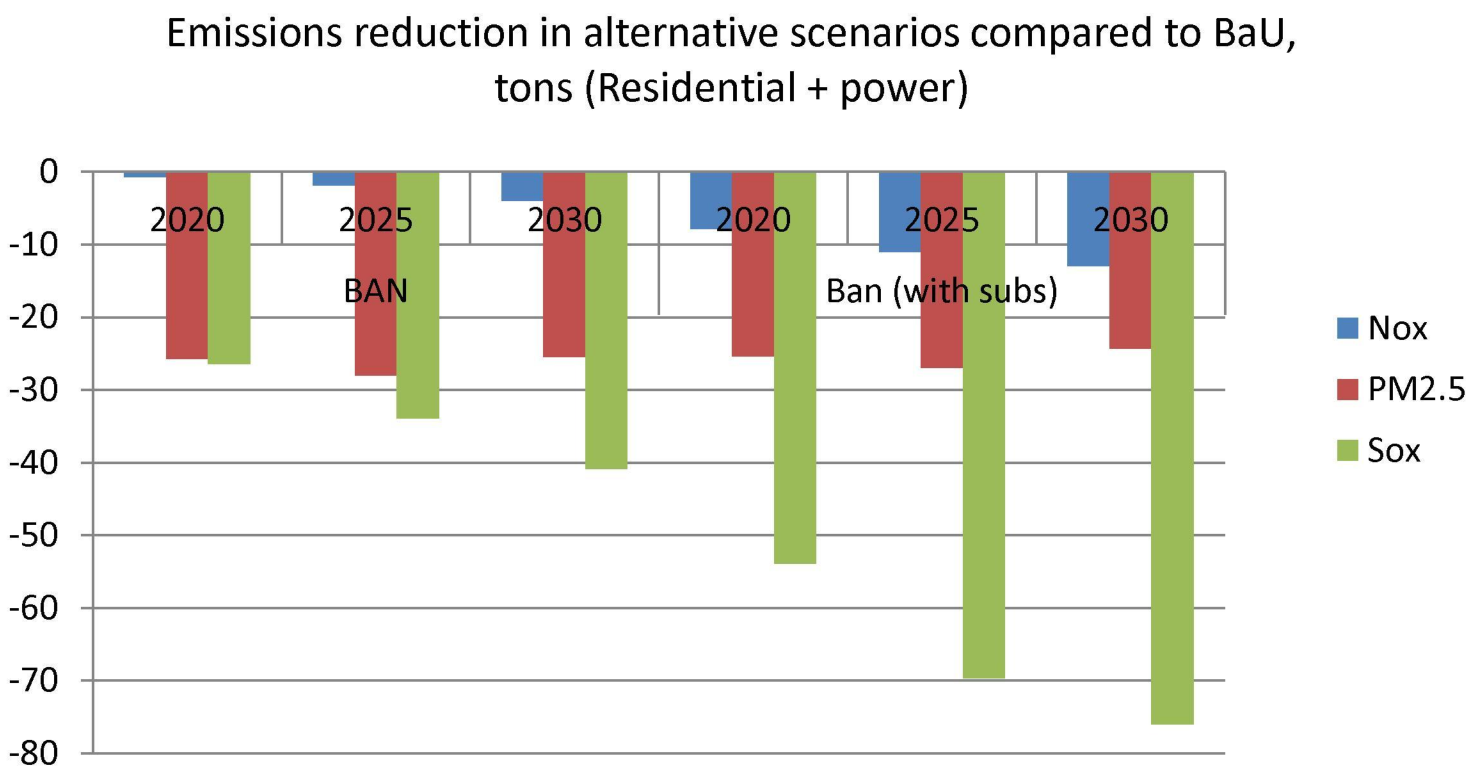
- Up to 73% of useful energy demand satisfied by retrofit measures for rural detached houses
- Significant impact from subsidies to retrofit measures
- Less savings for flat urban (up to 20%)

Detached rural houses



- Fuel mix in coal ban scenarios strongly depend on gas network
- Gas is still more viable compared to subsidized technologies (when there is not constraint on network expansion)
- Without gas network extension, heat pumps, electric heaters and district heating satisfy energy demand

Reduction of pollutant emissions



- Reductions of emissions of PM2.5 and SOx in coal ban scenarios
- Even if household coal combustion is replaced by district heating generated at coal heat plants, there are significant emissions reduction due to higher efficiency of combustion (and even more with pollutant control at power stations)

Conclusions

- The impact of **coal ban** on the fuel mix of the residential sector was studied with sub-nationally **disaggregated 16 regions** model of **Kazakhstan**.
- **TIMES-based** model represents all the steps of the **energy chain**, region by region: from the **extraction to transformation**, **distribution** and **end-use**.
- In the scenario with **coal ban**, it is substituted by **natural gas**, **district heating**, **biomass**, **electricity**.
- Additional **infrastructure** for network gas and district heating system is built.
- With **subsidies** offered, more retrofit measures.
- Significant **reductions** of emissions of **$PM_{2.5}$** and **SO_x** in coal ban scenarios, even with additional emissions generated in the supply side (e.g. coal based heating plants).
- In the **residential** sector **$PM_{2.5}$**, **NO_x**, **CO**, **CH_4**, **CO_2** reduce by 72%, 35%, 83%, 71% and 22% respectively in **BAN** (with subsidies) compared to **BaU** scenario.

Publications

Kerimray A., Rojas-Solórzano L., Amouei Torkmahalleh M., Hopke P.H., Ó Gallachóir B. P. (2017). Coal Use for Residential Heating: Patterns, Health Implications and Lessons Learned. *Energy for Sustainable Development* 40C (2017) pp. 19-30

Kerimray A., Kolyagin I., Suleimenov B. Analysis of the energy intensity of Kazakhstan: from data compilation to decomposition analysis. *Energy Efficiency* (Under Review).

Kerimray A., De Miglio R., Rojas-Solórzano L., Ó Gallachoir, B.P. Causes of energy poverty in a cold and resource rich country. Evidence from Kazakhstan. *Local Environment* (Under Review).

Kerimray A., De Miglio R., Rojas-Solórzano L., Ó Gallachóir B. (2017). Household Energy Consumption and Energy Poverty in Kazakhstan. IAEE Energy Forum. https://www.iaee.org/en/publications/newsletterdl.aspx?id=382

Kerimray A., De Miglio R., Rojas-Solórzano, L., Ó Gallachóir, B. (2016) Incidence of district heating and natural gas networks on energy poverty across Kazakhstan. 1st IAEE Eurasian Conference "Energy Economics Emerging from the Caspian Region: Challenges and Opportunities". Baku, Azerbaijan http://www.iaee.org/baku2016/submissions/OnlineProceedings/Proceedings_Paper_IAEE_final.pdf

THANK YOU FOR YOUR ATTENTION!

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List of contraints

Capacity transfer: The total available capacity is equal to the sum of investments at past and current periods plus capacity in place prior to the horizon

Activity definition: Equates an overall activity variable with the appropriate set of flow variables, properly weighted

Use of capacity: The activity of the technology may not exceed its available capacity, as specified by a user defined availability factor.

Commodity Balance: The disposition (consumption plus exports) of each commodity balances its procurement (production plus imports).

Efficiency definition: The ratio of the sum of some of its output flows to the sum of some of its input flows is equal to a constant (efficiency).

Flow share: Limit the flexibility, by constraining the share of each flow within its own group.

Peak: There must be enough installed capacity to exceed the required capacity in the season with largest demand for commodity by a safety factor (peak reserve).

User constraints: impose annual or cumulative bounds on commodities (emissions or reserves of fossil fuels), limit the share of processes in the total production of commodity; limit investment in a process (nuclear capacity), dictate a % of a fuel for electricity generation (renewable sources).

Constraints for refineries