Advanced stochastic optimization modeling of the water-energy-food nexus for robust energy and agricultural development: Coal mining industry in Shanxi province, China

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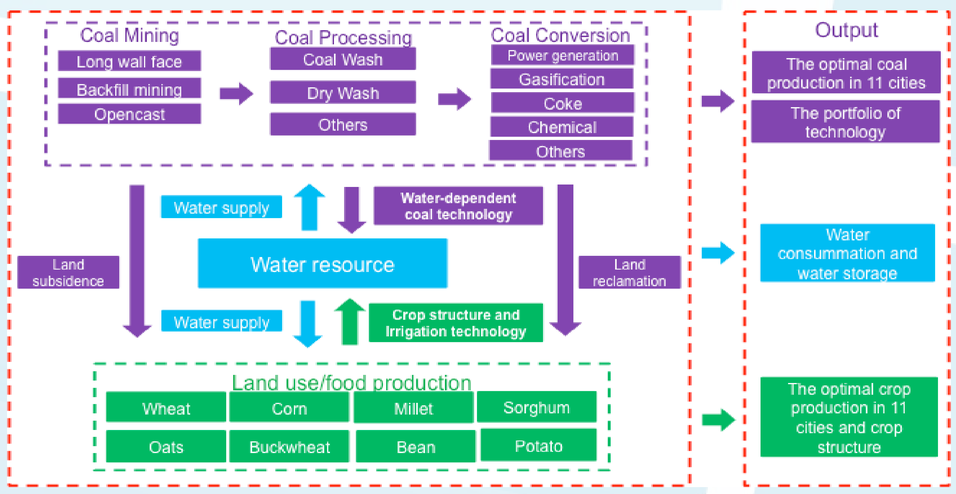
Water-energy-food security modeling under competition for and scarcity and uncertainty of natural resources

- The model is able to carry out an integrated systems analysis of interdependent energy-food-water-environmental systems under security targets while accounting for the competition to those systems posed by restricted natural resources under inherent uncertainties and systemic risks.
- The case study focuses on developments of coal industry and agricultural production in Shanxi province of China.

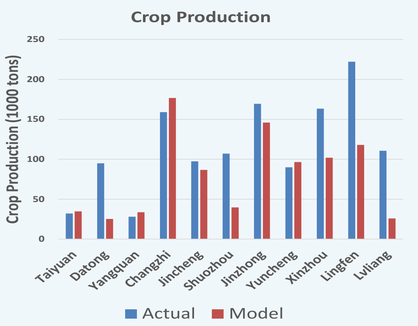


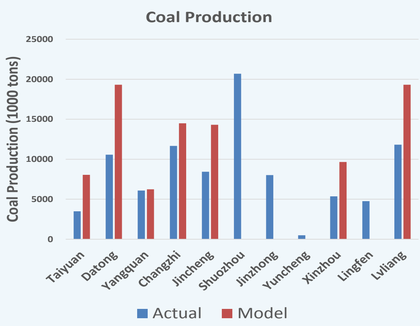
Problems associated with coal mining

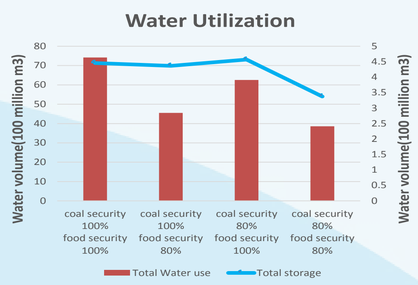
- Land damage: nearly 95% of coal production come from underground mining, and every mined Mt of coal has been estimated to result in 20 ha of subsiding land. Over the last 20 years the amount of farmland destroyed by coal mining has reached 692 thousand hectares.
- Uncertain provision and high demand for water: Coal-based industries - mining, washing, chemical production and power generation - are all extremely water-intensive, which introduces competition between coal production sector and other sectors.
- Water scarcity: In China average water resources are only about 1.7 thousand m^3 per capita, barely above the United Nations' water scarcity index.
- SO_2 emissions: The high sulfur content of most of the Chinese coal produces high level of sulfur dioxide (SO_2) emission, especially from coal burning power plants.
- CO_2 emissions: Coal consumption was responsible for three quarters of China's CO_2 emissions from fossil-fuel combustion in 2012.

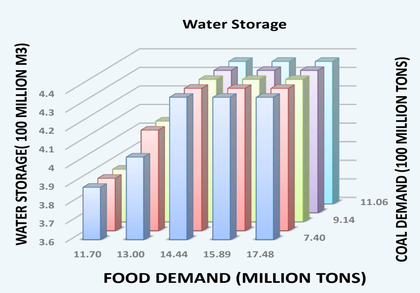
Policies addressing the problems

- It is being considered to impose an absolute cap on the greenhouse gas emissions from 2016, which means that the power plants will have to undertake more efforts towards emissions reduction.
- At the end of 2013, the Ministry of Water Resource (MWR) announced the plan of water for coal, which pertains to control the total water use by coal bases and power generation.
- The National Energy Agency announced a notice on the coal-to-oil and coal-to-gas projects, according to which the approval and ratification of the projects is possible only after detailed analysis of water resource availability and water demand of other water users, i.e., agriculture, households, industries, etc. New projects are implemented only if they do not compete for water with other economic activities in the region.
- In the beginning of 2014, the Government stressed the priority to improve rural livelihood and emphasized the target of minimum farmland in order to provide safe domestic grain production, i.e., ensure food security.

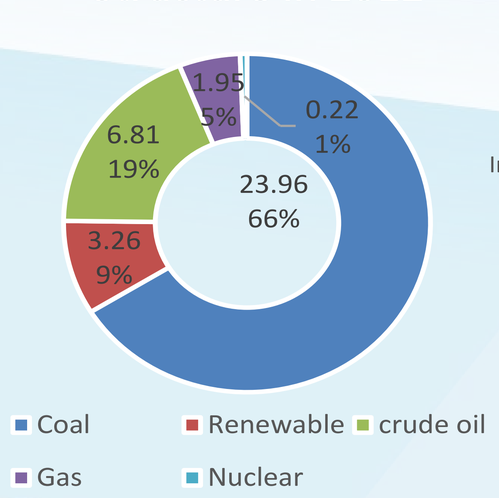


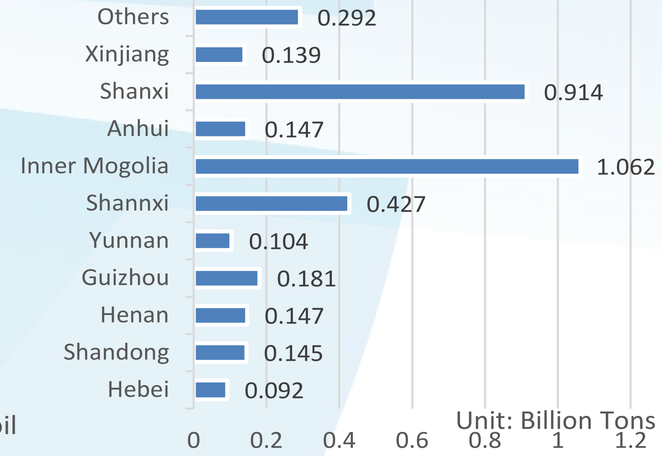






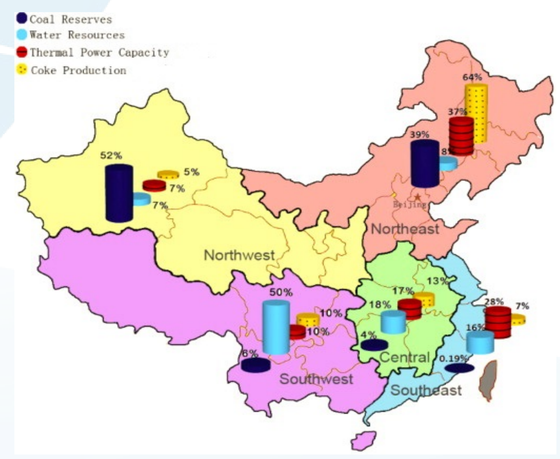
Energy consumption structure in 2012, China





Water scarcity ?

- In China, there is a huge mismatch between water resources and coal reserves. 53% of China's coal reserves locate in water scarce regions and 30% are in water stressed regions.
- Water shortage may become more prevalent and severe due to changing precipitation patterns from climate changes, for example, in such provinces as Shanxi, Inner Mongolia, which already have high water scarcity risk.



Robust water, energy, and food provision: water and grain storages, grain trading

- Some of policies regarding the negative impact from coal industry failed to address the issues in a systems analysis approach. This model allows a systemic way to deal with the development of coal industry under the energy, water, and food security interdependencies.
- The model is a stochastic two-stage optimization, which runs at different resolutions, e.g., coal mines, counties, prefectures, regions, the resolution depends on the availability of data. In this work the model is applied at resolution of prefectural level cities in Shanxi province.
- The model accounts for various coal mining, processing and conversion technologies, as well as for various types of crops in locations within the region. We consider existing technologies and those, which are only at the beginning of implementation or even in the research stage (e.g. various carbon capturing technologies). Import and export are included as a type of technology.
- The model permits spatially detailed analysis of sustainable coal and agricultural production expansion at locations (under competition for and uncertainty of natural resources) consistently with available national, sub-national, regional trends of energy and agriculture (land) demand calculated e.g., by MESSAGE and GLOBIOM models.

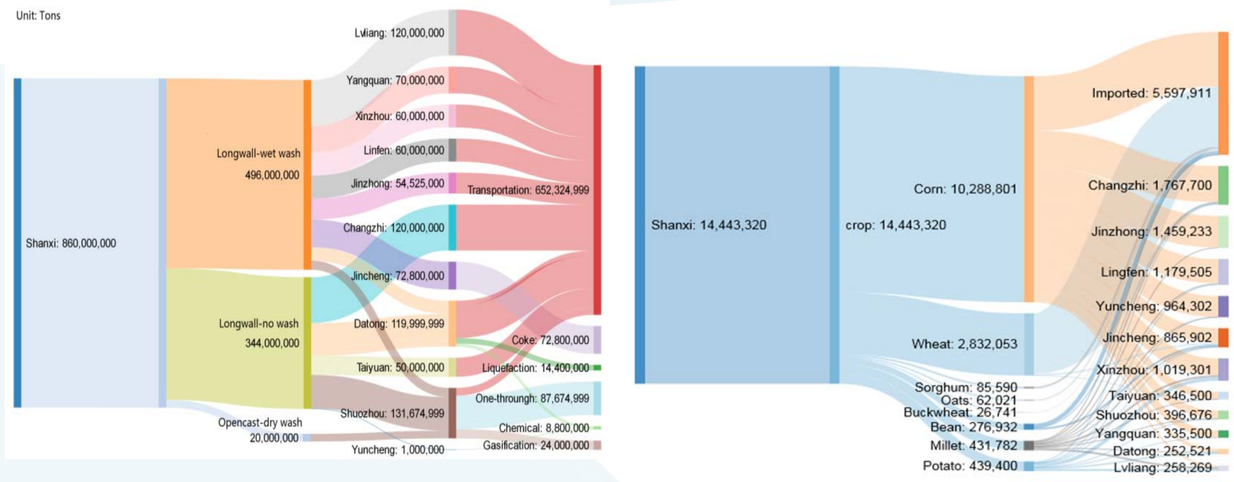


Figure: Robust production allocation: coal and agricultural industry

Reference: Xiangyang, X, GAO, J, CAO J, Ermoliev Y, Ermolieva T, Kryazhimskii A, Rovenskaya E (2015) Systems analysis of coal production and energy-water-food security in China. *Cybernetics and Systems Analysis*, 51(3):370-377.

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