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Analyzing water supply in future energy systems using the TIMES Integrated Assessment Model (TIAM-FR)

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ABSTRACT

Even though policies related to water and energy generally dealt with them separately, the two resources are highly interconnected. Energy is required to maintain water supplies while water is essential to produce energy. However, the models developed to estimate future water allocations and energy systems are usually uncorrelated.

In order to jointly consider water and energy uses, a water module has been added to the global TIAM-FR prospective energy system model. Water footprints for the processes in terms of withdrawals and consumptions were implemented in the model. This proposed TIAM-FR model shows how water issues are crucial in energy production and can constitute a tool to observe if future energy mixes could be plausible in regards of water availability.

Keywords: water-energy, long-term planning tool, TIAM-FR model

OVERVIEW

Water and energy are both considered as strategic issues in our societies that have to cope with numerous challenges. Depletion of fossil resources and increasing environmental consciousness are driving the actors of the energy sector towards improving the efficiency of existing technologies and developing new technologies to reduce environmental impacts. Some experts refer to water as the new oil, reflecting a growing concern about the availability and the sustainability of water resources.

While water and energy are highly interconnected, models to estimate the future development of water and energy systems are usually uncorrelated and deal with each resource separately.

- Prospective energy system models may be used to estimate the long-term development of the energy systems and future energy mixes.
- On the other hand, water models may be used to study future allocations of water in sectors such as agriculture, residential, industry, and energy.

To the best of our knowledge, no link between water models and energy system models has been established, which means that the computation of a shared optimum for energy and water resources is unachievable [1, 2, 3]. The current environmental approach in energy issues mainly focuses on reducing greenhouse gas emissions, commonly resulting in increasing use of technologies which provide a partial solution to air pollution issues but may worsen the water stress as they require large quantities of water. In the context of a growing world population with increasing demands and competition for water and energy, it is vital to develop models that include the interactions between the water and energy sectors to compute sustainable long-term management policies.

Water and energy issues have been jointly considered by integrating water allocations for energy purposes into the TIAM-FR prospective energy system model. The proposed model considers the link and dependencies between water and energy, thereby providing plausible developments of the energy system in regions where water is scarce or may become scarce. Water is incorporated in the model in terms of water withdrawal (*"water removed from any sources, either permanently or temporarily"* [4]) and water consumption *("water abstracted which is no longer available for use because it has evaporated, transpired, been incorporated*

into products and crops, consumed by man or livestock, ejected directly into sea, or otherwise removed from freshwater resources" [4]).

Water allocations related to the energy chain were implemented in the model according to two methods, a commodity approach and a process approach. The commodity approach relates to every energy process that uses water (mining, refineries, power plants, etc.), while the process approach relates only to electricity production (nuclear, coal power plants… etc.).

WATER USES

Water is present throughout the energy chain. On the upstream, water is used for extraction, refining and processing. It is also a key factor for the production of non-conventional resources (e.g. oil sands, shale gas, tight gas etc.), currently growing in the oil and gas markets. The quantities of water vary with the method put in place. For example, secondary oil recovery using water injection could require $600m^3$/TJ whereas primary recovery requires only $5m^3$/TJ [5]. The same applies for coal and uranium though quantities of water needed are highly dependent on the type of mine.

Water uses for power generation	Withdrawal	Consumption
Cooling system:		
- Open loop	+ + +	+
- Wet closed loop	++	+ + +
- Dry closed loop	0	0
Heat transfer fluid: water withdrawals or consumptions related to the main loop of the power plant are negligible compared to these related to the cooling system, therefore this water use will be disregarded.		
Emission control: CCS (carbon capture and sequestration) and FGD (flue gas desulfurization)	++	++
Gasification processes	+	+

Table 1: Water uses for electricity production

On the downstream of the energy chain, in the electricity production, four major uses of water were identified (see table 1 for an overview). Quantities of water used in the cooling systems are dependent on the kind of technology. As for new processes implemented to reduce the discharge of pollutants or greenhouse gases, they turn out to be high consumers of water: desulfurization systems increase by 10% the volume of water consumed, carbon capture nearly doubles it.

Hydropower has not been considered in this study. Though hydropower plants are by definition the main users of water for energy production, most of these plants do not consume water. Water consumption may be due to additional evaporation from the reservoir (if any), but as dams are also used for multiple purposes (irrigation, flood control, navigation) it makes it difficult to assess which part is related to electricity production.

THE TIAM-FR MODEL

Analyses carried out in this paper are based on the TIAM-FR developed by MINES ParisTech, Center for Applied Mathematics. The model is based on the TIAM model and the TIMES model framework developed by the ETSAP organization [6, 7]. TIAM-FR is a global model (divided into 15 regions) which offers a technology-rich representation of the energy system. The development of the energy system can be analyzed in a short-, medium-, long-term perspective up till the year 2100. The model is based on a bottom-up, linear-programming approach in which the technical optimum is computed by minimizing the discounted global system cost.

Each step of the energy chain from primary energy to final energy service demands (heating, lighting, travel, etc.) is identified in the model in terms of both economical and technical characteristics. Technologies to achieve these stages are called processes (extraction of fossil fuels, imports, processing of primary energy in final energy etc.). Energy carriers (primary energy, final energy, and useful energy), energy services, materials, cash flows and emissions are called commodities. The links between the commodities and processes are represented in a *Reference Energy System*; an example is shown in the Figure 1 where commodities are represented with an italic font and a light filling, while processes are represented with a normal font and a dark filling.

In the proposed model, water commodities have been linked to extraction, transformation and electricity production (processes framed in red).

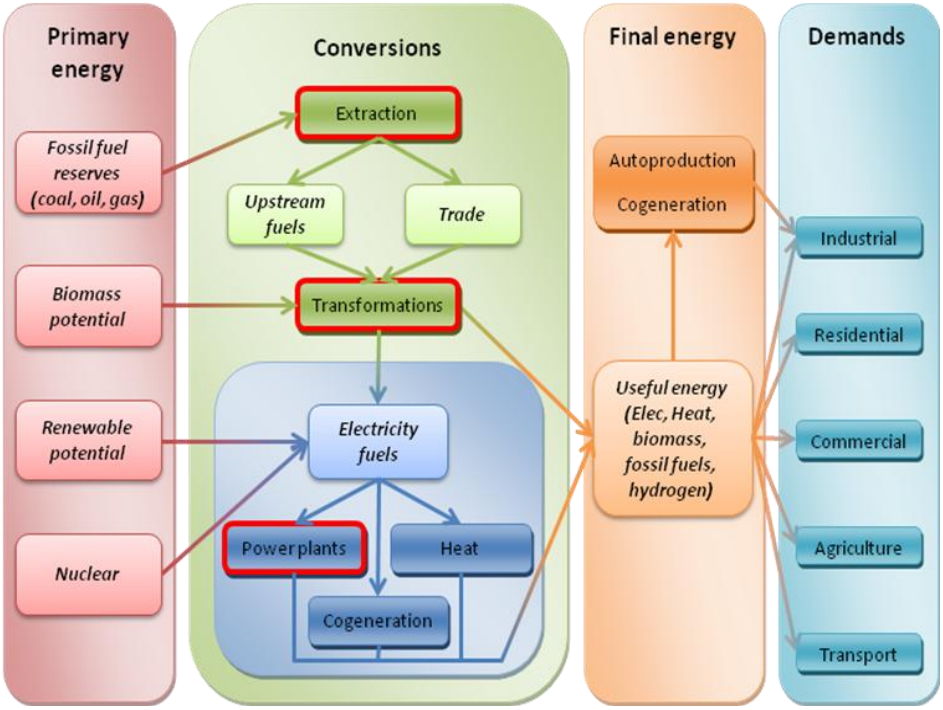


Figure 1: Reference Energy System

COMMODITY APPROACH

The commodity approach may be used to determine water withdrawals and consumptions of the energetic mix. Two types of commodities were linked to each process output, called water factors:

1. Water consumption: *WC
2. Water withdrawal: *WW

The star makes reference to the kind of water used as different kinds of water have been identified for open loop cooling systems while for every other process, only fresh water has been considered:

- B: Brackish water
- F: Fresh water
- G: Ground water
- M: Municipal water
- S Saline water

Water factors related to the upstream energy chain processes

Data related to water consumption for extraction were found in the literature [5]. Those depend of the kind of technology put in place (type of mines, processes used for oil extraction etc.). However, in the TIAM-FR model, all these processes are not identified so precisely, therefore it has been necessary to weight the water factors according to the different parameters they rely on. Ratios of the various mining methods used for coal and uranium extraction (conventional open pit, underground open pit and in situ leach) were needed to determine water factors for these extracting processes mentioned in the model. Various oil extraction technologies were also identified to adjust their water factors. Other parameters like the percentage of on-shore oil fields or the quantity of *produced water* extracted from oil and gas fields used (thereby reducing the net amount of water injected) were also taken into account.

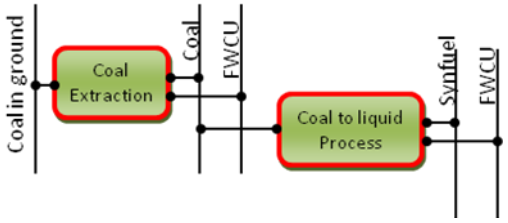


Figure 2: Upstream water RES with the commodity approach

Only one output commodity is related to those upstream energy chain processes: FWCU (*Fresh Water Consumption Upstream*), as shown in Figure 2.

Water factors related to power plants [8]

The main user of water in a power plant is the cooling system. Withdrawals and consumptions related to these technologies depend on the flow in the cooling system, and thereby on the power plant efficiency. Efficiency varies with the type of power plant (steam turbine, combined cycle etc.) and the fuel used (coal, gas, oil, and biomass). Indeed, the heat to release in the cooling system (Q) is related to the thermal efficiency (ρ_{th}) and the mechanical work (W_m):

$$Q = \frac{1-\rho_{th}}{\rho_{th}} W_m$$

Water withdrawal ($\omega_{withdrawal}$) needed to release this heat using an open loop cooling system is equivalent to the flow in the cooling system as those do not recycle water:

$$\frac{\omega_{withdrawal}}{W_m} = \frac{1-\rho_{th}}{\rho_{th}} \cdot \frac{1}{c_p \Delta T}$$

where c_p is the water specific heat and ΔT the authorized increase of temperature. There are no consumptions related directly to the power plant. However, as the EPRI pointed out in one of its studies [9], the increase of temperature is responsible for a substantial evaporation at the downstream of the power plant and may also affect river or marine life. Consumption of open loop systems has been assumed to be 1% of their withdrawal.

Water consumption for wet closed loop cooling systems depends on the rate of heat transfer made by evaporation (f_{latent}) and the water latent heat (h_{fg}):

$$\frac{\omega_{consumption}}{W_m} = \frac{1-\rho_{th}}{\rho_{th}} \cdot \frac{f_{latent}}{h_{fg}}$$

Withdrawals are needed to maintain a constant flow in the system. Indeed, water losses are caused by evaporation but also by blowdown, as the water evaporated exits the refrigerant in a pure vapor state, leaving minerals behind that will concentrate in the remaining cooling water. The cooling system and the condenser could thereby be damaged. To avoid these issues, a portion of the cooling water has to be removed and replenished with make-up water, which is determined by an acceptable level of concentration (n) [10].

$$\frac{\omega_{withdrawal}}{W_m} = \frac{n}{n-1} \cdot \frac{\omega_{consumption}}{W_m}$$

To allocate a water factor to these power plants, not only their efficiency has to be known but also the ratio of cooling systems (open loop, wet closed loop, dry closed loop) put in place in the different regions available in the model as well as parameters like the allowed increase of temperature.

For some power plants, the implementation of FGD or CCS processes has also to be taken into account, as it will increase substantially their water factors. The same applies to IGCC power plants, as water is used for their gasification process. Some EPRI and DOE[1] studies evaluated water withdrawals and consumptions related to those technologies [1, 9, 11]. Thus, the overall water factor for each process, in each region, takes into account all these parameters and two kinds of water factors, withdrawals and consumptions of different kinds of water were attributed to them, as shown in Figure 3.

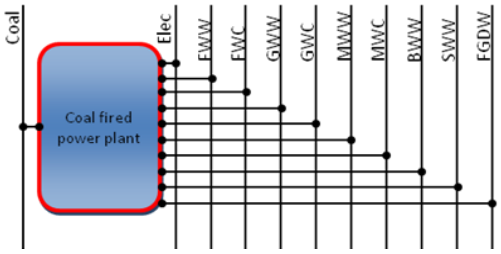


Figure 3: Electricity production water RES with the commodity approach

The last commodity, mentioned in the figure, FGDW, represents withdrawals and consumptions (as they were assumed being equivalent) related to the use of flue gas desulfurization.

PROCESS APPROACH

The process approach applies only to cooling systems for new facilities. Instead of allocating water factors directly to the power plants, a new output commodity, Q, is linked to them, representing the amount of heat that has to be discharged in the cooling system. These new commodities are determined according to the source of heat (combined cycles operating with gas, steam turbines using subcritical coal etc.). New processes related to different cooling systems and different kinds of water are also considered in the model. By requiring that the

[1] US Department of Energy

amount of waste heat (Q) is zero, the model is required to use these processes.

At this level of implementation, the process approach gives identical results as the commodity approach. But further improvements have been made, allowing the model to be more flexible about the concept of water. Indeed, wet and dry closed loop cooling systems induce lower efficiency than open loop cooling systems. Therefore, a quantity of electricity related to the quantity of heat to discharge by the cooling process is needed for them in the model, as shown in Figure 4 .

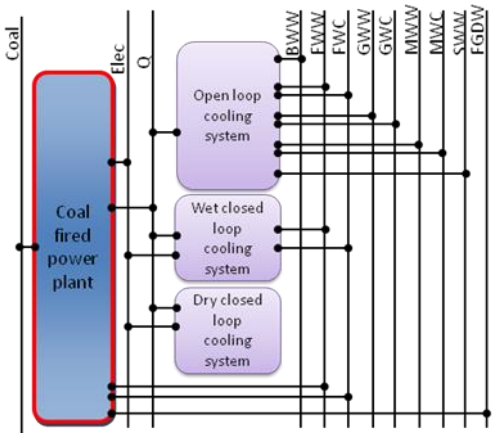


Figure 4: Water RES with the process approach

Upper bounds of open loop cooling systems activity have also been established, equivalent to existing processes currently put in place in regard of current incentives for these kinds of cooling systems as well as lower bounds of use of closed loops (wet and dry). It is now possible to leave the choice of cooling systems uses to the model rather than imposing ratios. For a region where water is already scarce, like the Middle East, scenarios of maximum water consumption have been established. With the process approach, the model is able to decide between processes without use of water like photovoltaic or wind energy and the kind of cooling system being used.

RESULTS

Considering water resources to be unlimited, a *Business as Usual* (BAU) scenario concerning the use of processes was created. The scenario showed the evolution of water allocations; it also showed that worldwide water consumption due to electricity generation may triple by 2050. Additionally, a massive introduction of flue gas desulfurization technologies was found to have a large impact on the water consumption of coal power plants. Such systems might indeed represent 11% of water consumption of these power plants in a scenario where all new coal power plants are installed with these technologies. The impact on water supply with climate constraint scenarios was also studied. These scenarios aim to improve the use of Carbon Capture processes, which increase the power plants water consumption by almost 90%; thus these energy mixes may consume almost four times more water than the current mix. The study further pointed out that even if cooling systems may contribute to high levels of water consumptions, extraction technologies may together represent nearly a third of the water consumption in the overall energy chain.

Stability of the energy mix under limited consumption of fresh water showed that the energy mix is highly dependent on water. An upper limit of water use was defined for each region, according to which the use of processes was evaluated. The constraint on the maximal use of water was found to have a particularly high impact on the electricity generation with the *commodity approach* and the cooling system choice with the *processes approach*. These results consolidate the importance of considering the interaction between the water and energy sectors.

CONCLUSION AND PERSPECTIVES

Scenarios foreseeing future energy mixes to meet environmental policies commonly do not reflect consequences on the water supply. The study showed that worldwide electricity generation may double by 2050, with an energy mix which may consume almost three times more water than is currently being consumed. As such water consumption levels may prove to be unsustainable; the link between water and energy needs to be taken into account when estimating the development of the energy system.

The proposed TIAM-FR model is a first step towards changing the perception of water in energy models in order to find a global optimum considering both water and energy uses. With this model, it is possible to include environmental considerations and water use throughout the energy chain. Further developments will focus on including other water users (agriculture, residential, industry) in the model in order to perform a global comprehensive analysis of both water and energy supply.

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REFERENCES

[1] DOE/NETL. Estimating freshwater needs to meet future thermoelectric generation requirements. 2009 update.

[2] A. Mercè Rio Carrillo and C. Frei. Water : A key resource in energy production. *Energy Policy*, 37:4303–4312, 2009.

[3] *World Water Development Report*. World Bank, 2010.

[4] EEA (European Environment Agency). Multilingual environmental glossary. http://-glossary.eea.europa.eu/EEAGlossary/W.

[5] P.H. Gleick. Water and energy. *Annual review if energy and the environment*, 19:267-299, 1994

[6] R. Loulou and M. Labriet. Etsap-tiam : The times integrated assessment model, part i : Model structure. *CMS*, 5:7–40, 2008.

[7] M. Gargiulo. *Getting Started With TIMES-Veda, Version 2.7*. ETSAP, May 2009.

[8] S. Bouckaert, S. Selosse, A. Dubreuil, E. Assoumou, and N. Maïzi. Implementing water allocation in the tiam-fr energy model. In *11th IAEE European Conference, Energy Economy, Policies and Supply Security: Surviving the Global Economic Crisis, Vilnius, Lithuania*, August 25-28, 2010.

[9] EPRI (Electric Power Research Institute). Water & sustainability (volume 3): US water consumption for power production – the next half century. 2002

[10] SPX Cooling Technologies. Cooling tower fundamentals.

[11] DOE/NETL. Water requirements for existing and emerging thermoelectric plant technologies. August 2008 (April 2009 Revision)