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Integration of Energy and Resource Flows

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The continuing increase in the world population during last years has placed increasing pressure on the demands of world society. Industrial, construction and agricultural production has been under considerable pressure to cope with the population development and growing demands. This increase requires a large and continuously growing supply of energy and water delivered mostly from reserves of the natural resources. In the case of energy so far mainly fossil fuels are still used. The accelerating development of countries with large populations, such as China, India, Nigeria and some others has resulted in increased demands on agricultural production and processing, which in turn have resulted in further increases in energy and water demands. This sharply increases in cost and many cases of shortages of all forms of energy and water. This paper reviews the main trends in the flows of energy and water supply, paying attention also to the concept of virtual water, and draws conclusions for directions of possibly promising future research and development efforts.

1. Energy Demands and Energy Flows

The resources for energy supply have been limited; however the demand projection is a continuous growth - Figure 1. Clean water availability is limited as well and above all it requires energy to be delivered. The major sources are still fossil fuels, supplemented by nuclear power and renewables. A key task is to deliver the resources to the demand locations. This creates logistic and also political problems. Projected grows of China consumption seems to double the present values – Figure 2.

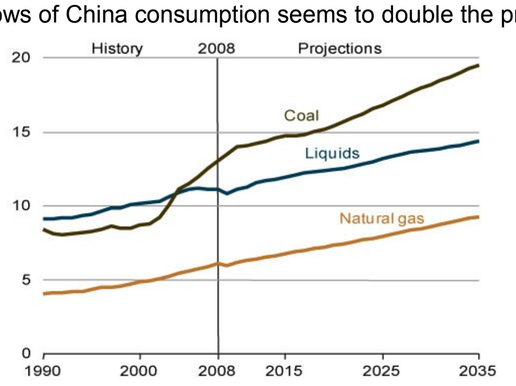

Figure 1: World Energy CO_2 emissions related to fossil fuels in 10^9 t (EIA 2012a)

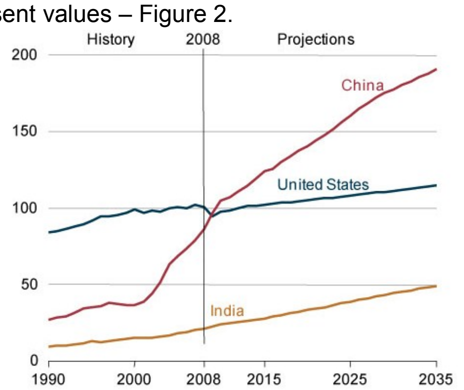

Figure 2: Projected energy consumption in China, the US and India, in 1.055 10^{15} J (EIA 2012b)

Another crucial problem has been conversion of various kinds of energy. As examples can serve Figures 3 and 4 presenting an analysis of the situation in the USA.

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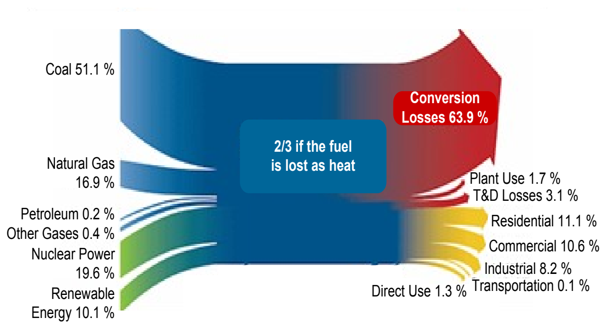

Figure 3: US Balance – Economy wide losses (CLEANENERGY, 2012)

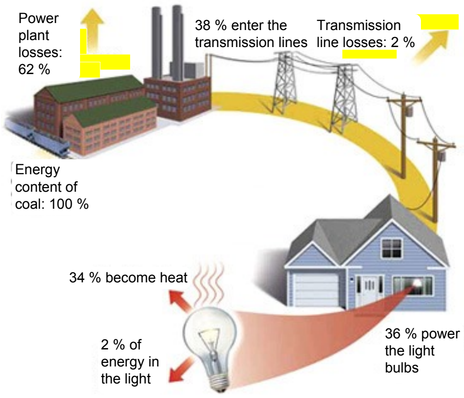

Figure: 4 US Losses for Electricity Conversion and Transmission (ENERGY Literacy.com, 2009)

Fossil fuel resources and delivery has been of paramount importance to industrialised countries and cause considerable struggle resulting in many conflicts. Nuclear energy can be generated in the region of the needed consumption. However, it raises safety and environmental issues. Renewable sources can be harvested inside or close to the region of consumption. However they have problems with variable availability in time, intensity and logistics – all interconnected see e.g. (Nemet et al, 2012).
To illustrate the size of energy flow and example of LNG is used (Figure 5). Flows of comparable sizes are executed by crude oil, refining and petrochemical products.

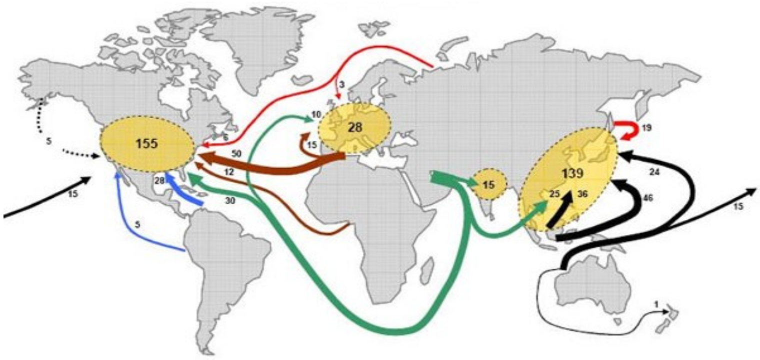

Figure 5: A forecast of World LNG Trade in Mt for 2015 (International Energy Consultants, 2012)

2. Water Demands and Water Flows

A similar situation (Figure 6) has been developing in water and fresh water supply, and waste water minimisation. The first water related studies were presented by Allan (2003a) and also analysing the water political impacts Allan (2003b). They were further extended by Chapagain and Hoekstra (2003) specifiing water footprints and virtual water as the volumes of water required to produce a commodity or service, water embedded in an economic good throughout its production and manufacturing process. These studies raised the issue about virtual water: "How much water can be saved (locally) by importing a commodity instead of producing it ourselves?" (Hoekstra and Hung, 2005).
The global dimension of water consumption and pollution shows that several countries heavily rely on water resources elsewhere (e.g. Mexico depending on virtual water imports from the US) and that many countries have significant impacts on water consumption and pollution elsewhere (e.g. Japan and many European countries due to their large external water footprints).

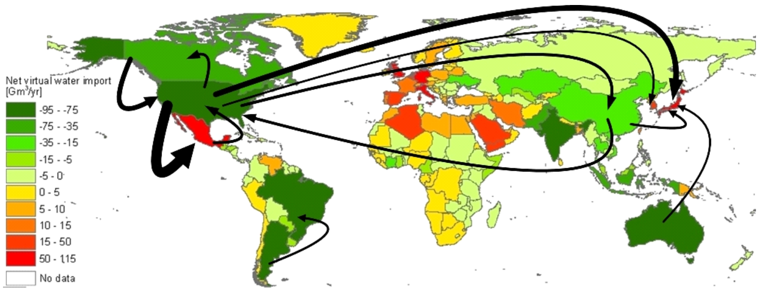

Figure 6: Main directions of virtual water flows (Water Footprint Network (2011a)

This has been also related to industrial and agricultural development as well as increasing civic demand and consumption. Water supply has been very closely interconnected with the energy. Water is very often used hot or chilled which requires energy. Water treatment, delivery, reuse, regeneration and recycling demand energy as well (Klemeš, 2012), see Figure 7. However, also the production of bio-flows can demand considerable water footprint. E.g. Chiu et al. (2009) indicated that bio-ethanol's water requirements just for the irrigation range up to 2,140 (L water)/(L bio-ethanol). In the EU, in 2007, approximately 44 % of water was used for energy production, 24 % for agriculture, 17 % for public water supply and only 15 % for industry (EC, 2007). However, they are some issues and restriction of virtual water trade specified by Water Footprint Network (2011b):

- Adequate foreign exchange revenue and social absorption capacity
- Abandoning the paradigm of food sovereignty
- The alternative goods produced must be marketable
- Good transport and infrastructure in rural areas
- Virtual Water Trade might be accompanied by a process of centralization and lead to a growth in government power
- International Virtual Water Trade is favoured by EU and US agricultural subsidies, while regional South-South trade is obstructed
- Besides ecological advantages for the water balance, ecological disadvantages can be expected
- The concept defies economic facts and rules of the world market

3. Observations, Suggestions and Potential Solutions

a) Transporting biomass (or bio waste) results in serious loss of energy value (not energy content, but value)
b) Even when transporting high-energy-density carriers as crude oil, losses are significant
c) The sheer magnitude of the shipped flows is huge
d) Translates to huge absolute losses
e) Energy and water should be sourced as close as possible to the location of use

They have been considerable benefits of sourcing regionally:
(i) Short-medium term: direct energy savings from transportation
Substantial
Easily quantifiable
(i) Long-term and strategic
Improved supply security (quantifiable, but difficult)
Eventual higher employment locally (quantifiable, but difficult)
Avoiding/mitigating conflicts – not easily quantifiable, however expected to improve safety and save cost of destruction and costs for military spending

What solutions improving the state-of-the-art can be offered by advanced engineering? The solution of the energy and water flows on the global scale demands enormously extensive models fed with the more data. To the some scale this can be dealt with, however the major problem on global forum is political interests of various key players.

4. Initial Steps on the Road to Success

Based on the analysis of the present situation a traditional and well rehearsed engineering bottom to top approach is suggested.

a) Huge and growing energy and water flows are the reality
b) Energy flows are mainly by carriers, but also as virtual energy in products
c) Water flows are mainly as virtual water
d) These flows are subject of considerable losses and a potential danger for the environment – both during the flow and by potentially influencing the regions balance
e) They can be subject of accidents and even terrorist attacks
f) A research challenge is how to reduce them

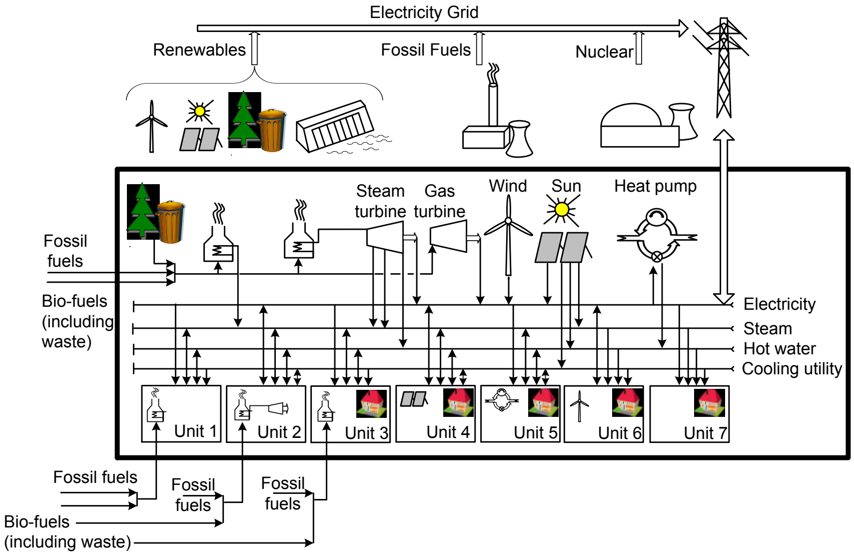

Figure 7: Total Sites exploiting renewable energy sources mainly locally produced (produced (Varbanov and Klemeš, 2011)

There have been very successful real life studies and even implementations delivered for Total Sites:

(i) Starting from traditional industrial complexes (Klemeš et al., 1997)
(ii) Extended Total Sites – covering industrial complexes and neighbouring smaller industrial, civic residential, business, service and even agricultural complexes (Perry et al, 2008)
(iii) Total sites exploiting renewable energy sources mainly locally produced (Varbanov and Klemeš, 2011) – see Figure 7.
(iv) Regional sites, considering a wider scale consumption and especially renewable supply based on biomass (Lam et al, 2011)
(v) Specific largely isolated sites as island and remote regions (Bandyopadhyay, 2011)

A methodology has been under progressing development for both energy and water supply and for optimisation of emission/effluents treatment flows. The main guiding principle is to minimise the net resource intake/demand of the considered systems at each level (Narodoslawsky, 2010). One may argue that resource recovery can be efficiently performed at the higher levels of this hierarchy. This may be true for smaller distances. However, with increasing distance, the energy overheads of transporting energy and water resources are likely to outweigh the potential benefits.
As an example, albeit still on a demonstration scale can serve Güssing in Austria – Figure 8. As part of the model region "ökoEnergieland" (Eco- Energy Land) Güssing, theyare operating demonstrational plants of system relevance in Güssing and Heiligenkreuz (Burgenland, Austria), which meet the energy supply of a whole region.

Example:
Güssing, Austria
Area: 49.31 km^2
Population: 3,798

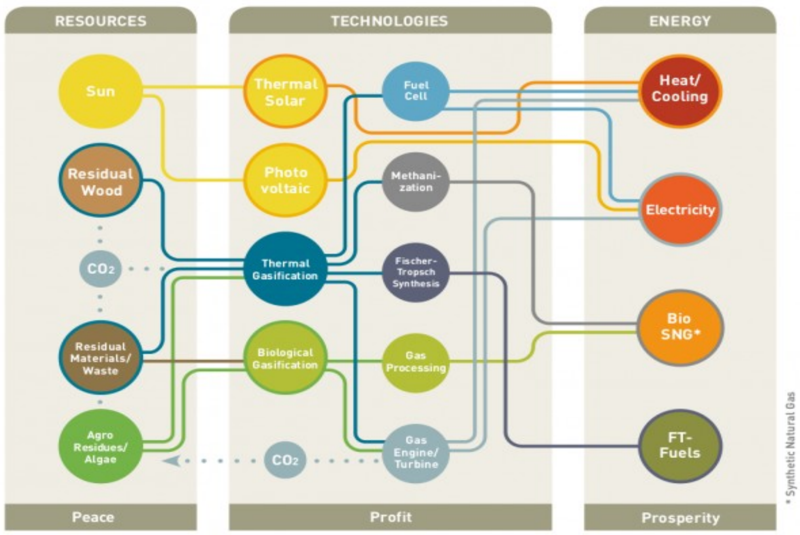

Figure 8: A demonstration regional site minimising global energy flows and long haul energy flow losses (Güssing Renewable Energy, 2011)

Some other steps in this direction have been presented dealing with Denmark (Clean Techies, 2012), Portugal (Krajačić et al, 2011) and Ireland (Connolly et al, 2011).

5. Conclusions

Conclusions based on the global energy and water flows can be summed up as:

(i) The influence of energy and water flows on the environment is very substantial
(ii) A lot of research effort has been paid to individual process or even parts of process
(iii) To target growing research effort to all level of energy/water flows is a very important part of the struggle for sustainability
(iv) They are some constrains caused by business and political interests
(v) The methodologies exploiting the renewables have been under fast developed and going to offer more sustainable solutions

Some suggestions for the future research can be made:

a) Renewables are providing a potential for sustainable and self-sufficient regions
b) However, they have to be used in efficient way (see e.g biomass transport from Western Canada to Europe, or wind generated electricity transferred across Europe)
c) A good chance offers wider integration using waste/unusable heat/water from one process/unit to the others on the site/district/region
d) A proper research methodology is important
e) They have been already numerous and promising works in this field, however more targeted research effort is needed

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