Developing the WORLD6 integrated global model; causally linking natural resource use, energy use, commodities, population dynamics, health impacts, governance dynamics and the economy

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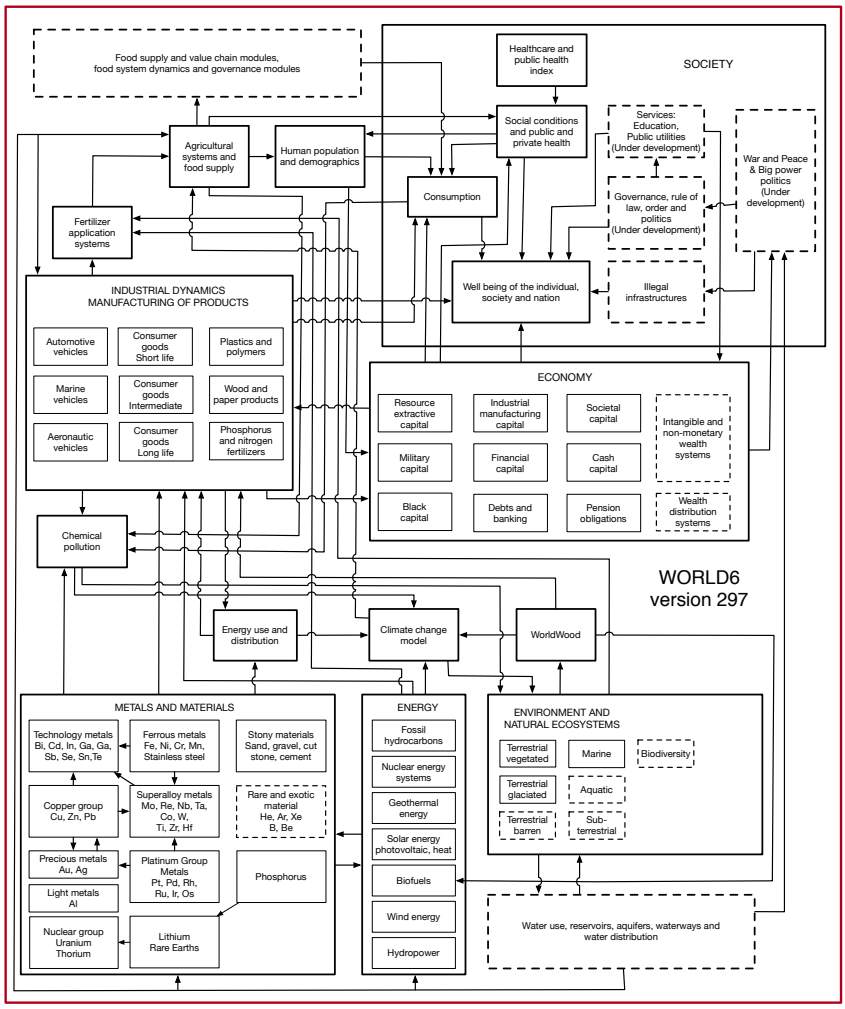
The WORLD6 model is a tool that can be used to explore possible strategies and help develop adequate policies and strategies for the future. The integrated dynamic model system links the long term availability of natural resources, industry, materials, market mechanisms, economy, food, population, natural environment, governance and sustainability on a global level.

WORLD6 model outputs are analysed to assess the long-term sustainability of our society and ultimately it is shown that the model tool can help shape policies for the future. Examples of how the WORLD6 model system is used and what outputs may look at are presented. The WORLD6 model has been subject to a number of tests against observations and some of the results of these tests is presented. The model can be shown to have the ability to reconstruct past history (1850-2015) fairly well. The relationship between extraction, supply and recycling and the time of population maximum plays an important role for how the supply situation will develop and to evaluate risk for scarcity. In the past decades, many researchers have concluded that the world has reached the confines of the planetary capacities and boundaries, resulting in the realization that humanity may one day become resource limited.



In 1961, Forrester created the first draft of a system dynamics model of the world's socioeconomic system, World1, in response to a challenge by the Club of Rome (Forrester 1961). Forrester refined this to become World2 (Forrester 1969). The Club of Rome initiated further work into this issue and Meadows et al., (1972) published the outputs from their World3 model and made famous by the book "Limits to growth" in 1972. This type of models based in system dynamics have gone through 3 development phases:

- 1961-1971; **World1-World2**; Forrester team (1961-1971), MIT; Industrial dynamics, urban dynamics, world dynamics, the first pioneering basic concept for how a World model may be put

together. The model was very simplified because of computational constraints of the computers available at the time (Forrester 1961, 1969, 1971).

- 1972-2004; **World3**; The Meadows team (1972-2004), MIT; World dynamics and limits to growth. The model was more elaborate than World2, significantly better parameterized and described in a book "Dynamics of Growth in a Final World" (Meadows et al., 1972, 1974). The model had large simplifications because of computational constraints of the computers available at the time.
- 2011-2017; **WORLD4-WORLD6**; Sverdrup team (2013-2016), University of Lund and University of Iceland. A world dynamics model, WORLD6 was developed. It has reality-based market mechanisms and simulates commodity and individual resource price dynamics internally. WORLD6 handles the global economic and financial development, and captures economic cycles of growth, stagnation, and decline. The modules are linked inside so that different resource and policy aspects can be addressed. T The big difference is the inclusion of social modules and that they are linked to economy, resources, health and demography. The resources are treated individually, as they serve very different functions in society.

The model reproduces observed data really well (r^2 in the range 0.80-0.97) all the extraction rates, supply rates and market prices for all the materials and metals listed. Figures 2-4 shows some examples of the types of outputs that can be made with the model. The full paper contains many more.

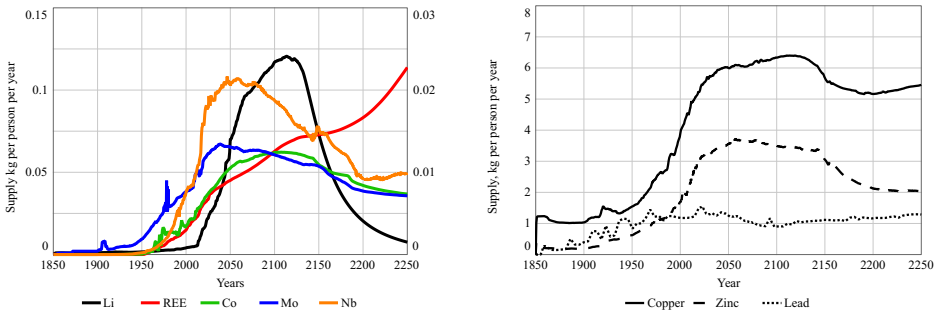


Figure 2. The supply for Li, REE, Co, Mo and Nb and Cu, Zn and Pb, using outputs from the WORLD6 model.

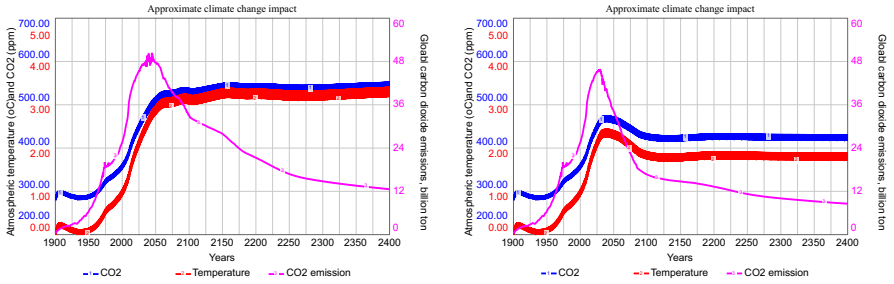
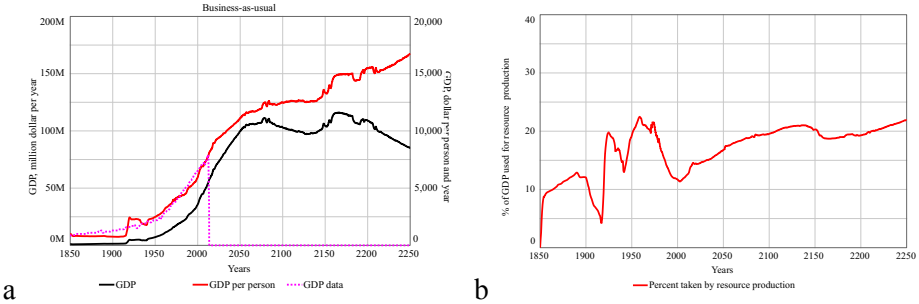


Figure 3. Comparing climate change outcomes for the base case and Maximum 2°C global warming by reducing fossil fuel use by 90% from the WORLD6 model.



a b

Figure 4. The global GDP as calculated using the WORLD6 model (a) and the fraction of GDP used for extracting natural resources (b).

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