The nexus of international policies for climate protection and resource efficiency

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the future needs to be shaped

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Author Note

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Abstract

A combination of qualitative, process, and system dynamics modeling of the nexus of climate protection and resource efficiency policies reveals that a global transition towards renewable energy would be possible, but with the availability of certain raw material resources playing a crucial role. The process modelling approach reveals that while known global reserves of relevant abiotic raw material resources (e.g., copper, silver, etc.) relevant for renewables would be sufficient the capacities (investments by companies for a relatively short period with a high peak) to extract and process them could become a constraint.

The model compares the scenarios from the World Energy Outlook (WEO) with the ambitious scenarios from the RESCUE-project of the German Environment Agency. For the long-term stable provision of renewable energies, we need a circular economy with a maximum of recycling to keep relevant raw materials in loops. Shifting to renewable energy sources also includes using more bioenergy. Therefore, we also modeled the global potential for biotic resources in the future after their use for food and industrial feedstock and with their potential for cascadic use. The view on biotic resources shows the urgent need for different consumption patterns with less consumption of animal products. This change of behavior could provide synergies for reducing resource and energy consumption in other areas as well - and it could support an overall reduction in the need for energy alongside shifting to renewable energy. Here, material efficiency in industry can help reducing energy needs, too.

With qualitative models we also have examined the lever for policies and with a general system dynamics model we showed the logic of rebounds from economic growth, resource consumption, and winners and losers from a shift of resource extraction to resource recycling. Thus, the future needs to be shaped.

Keywords: climate change, resource efficiency, world energy outlook, system dynamics, theory of constraints, biotic resources, energy transition, renewable energy, LULUCF

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While climate change and the strategies to mitigate it are well examined, the role of resource efficiency with regard to the energy consumption for the use (mining, processing, recycling) of resources and their availability for a transformation towards renewable energy deserves further exploration (Barret; Scott, 2012; Elshkaki; Shen, 2019). And since the availability of critical resources for renewable energy and its application needs to be seen globally, the underlying project of this work looks at international policies. The project was funded and initiated by the German Federal Environment Agency and will be finished by the end of 2021. This paper is a presentation of first results.

Climate change mitigation

The combustion of fossil fuels, the processing of resources like concrete or steel, and the global agriculture are the main contributors to the overall greenhouse gases emissions (Hatfield-Dodds; et al., 2017).

To look at agriculture includes the methan emissions from cattle and the use of mineral fertilizer with its own emissions of nitrious oxide as a greenhouse gas as well as the competition for land with forestry.

Growing woods can serve as a sink for carbon dioxid. The material use of wood can substitute abiotic resources like steel or concrete that cause a lot greenhouse gas emissions during production. Its use also prevents the CO2 emitting natural decomposition of wood in the forest as well as it makes room for new growing trees. However, even after a cascadic use wooden materials they like the direct energetic use of wood would substitute oil and gas as long as fossil fuels are are still part of the energy mix. Here in particular we face dynamics over time that are predestined for a system dynamics approach.

One objective of this project is to explore ways to substitute the use of fossil fuels for renewable energy including so called power-to-liquid/gas (UBA, 2016) for the chemical industries. Of course, that process depends on the developments of the global population and its consumption. The consumption defines the need for energy as do the technological choices.

Resource efficiency

Technological choices around the world do not define just the direct need for energy but also the used amount of primary resources that have their own climate impact. Reuse, repair, recycling, prolonged life cycles and sufficiency as the option to require less material wealth define the need for resource and thus the need for energy for mining, transportation, processing and recycling (IRP, 2019).

The model looks at land use, land use change and forestry (LULUCF) and the effects of using wood, the latter not just energetically but also as a substitute for other energy intensive materials like concrete, steel or gypsum and with a potential cascading use until its final energetic utilization (Roe; et al, 2019). The model also looks at the consumption of animal products around the world which defines the need for land for fodder production that competes with the area available for forestry or biotic resources as feedstock or for energetic biogas.

The productivity of land use depends on parameters like the use of natural or mineral fertilizers, the farming practices, the overuse and soil degradation (e.g. by short term utilization of plant residues for biogas), or the effects from climate change (droughts and floodings).

The ICARE model family

The project started with a qualitative model (Qualitative ICARE Model) to explore the interconnections between climate protection and resource efficiency. ICARE stands for Interactions between Climate Action and Resource Efficiency. It then added potential international policy instruments for both and continued to explore them in a quantitative simulation model (Quantitative ICARE Model) accompanied by a smaller simulation model (yet untitled) that examined some game theoretical aspects.

The Qualitative ICARE Model

The Qualitative ICARE Model was used to exploratively collect the arguments around the question how resource efficiency and climate protection are interconnected. While descriptive models try to use as few factors as possible to describe a well-known system, the explorative approach uses different techniques (Neumann, 2015) to ask for crucial influences in a potentially very large model. The comprehensive Qualitative ICARE Model (figure 1) was developed together with experts from different fields.

Using the iMODELER software a qualitative model does not just draw a cause-and-effect relation between two factors but also allows to weight their direct impact in comparison to other factors. After weighting all connections so called Insight Matrices for each factor or their tornado chart view (figure 2) compare the short-, medium- and long-term impact of factors. The impact is the result of the weighted impulse along all the cause-and-effect chains and running through the feedback loops. The approach is unique (Neumann, 2015) with the concept of fuzzy cognitive maps (FCM, McNeill; Freiberger, 1993) being the closest comparable to it.

A qualitative model does only show whether something has a comparable high or low decreasing or increasing effect compared to other influences. It does not show the quantitative change over time as do quantitative simulations models. So, while the qualitative model indicated potential synergies and trade-offs also from feedback loops some aspects required a quantitative exploration.

The Quantitative ICARE Model

The aim of the descriptive Quantitative ICARE Model was to look at the global transition towards renewable energy, its need for critical resources (coppers, silver, aluminum, rare earth minerals, etc.), and the accumulating effects on greenhouse gas emissions from the different paths of a transition. An additional module examined the global potential for biotic resources, the so called LULUCF module.

The energy module of the ICARE Model.

To have a baseline for the potential development of demand for energy from different sectors around the world we chose the World Energy Outlook (WEO) 2015 by the International Energy Agency (IEA). The world is covered with regions like North America, Africa, East Asia, etc. Sectors are mobility, industry, buildings, etc. Sources for energy are gas, coal, nuclear, onshore/offshore wind, photovoltaics, electrolysis from power-to-gas/liquid, and biomass. Power-to-gas/liquid is globally traded and used as a feedstock for the chemical industry, for synthetic fuels, and for electricity from electrolysis in times with no wind nor sunshine.

To cover the need for repowering of older installations the model runs from 1990 to 2100. To include the seasonal change of sunshine the model simulates monthly steps. To include the need for energy storage because of random lack of both sunshine and wind it uses a smart look-up function that relates the need for electrolysis capacities to the share of renewables. The model is also developed with the iMODELER software using system dynamics as the core but also adding special process and resource factors that allow for easy modelling of the competition of process for limiting resources. Instead of lengthy if-formulas that describe how a process can run if other processes have left resources in each time step process factors just need to know how much of a resource they need for one unit (figure 4) and on which rank in a priority list they stand and then they calculate the possible output for each time step. The cockpit automatically indicates so called constraints (see the theory of constraints by E. Goldratt, 1997) - resources, or a stop criterion that limit the output. That way used and unused capacities, the lack of capacities, the constraints from available resources and the capacities to implement renewables can be shown (the grey area behind the simulation curves in figure 4 indicates the constraints for each time step).

Since the price for energy is very important to implement policies, the model also examines the macroeconomic costs of the transition (Burchardt; et al, 2018) comparing so called margin costs of fossil energy with the depreciation of renewables considering different value creations of the implementation compared to the import/export of fossil fuels.

Next to the base scenario from the WEO we have adapted ambitious scenarios from the RESCUE project (UBA, 2019) of the German Federal Environment Agency to the rest of world in particular scenarios in which the whole world transitions to renewable energy until 2050 and one in which parts of the world transition 10 years later.

The LULUCF module of the ICARE Model.

To explore the future potentials for biogas, for a substitution of steel and concrete through wooden materials, and for the capturing of carbon dioxide together with the greenhouse gas emissions from cattle, mineral fertilizer and energetic use of biotic resources all with regard to the need for food for a growing world population we have developed a module that simulates the land use of the regions from the WEO using the data from the Food and Agriculture Organization (FAO). The model can run scenarios on different parameters, for example the consumption of animal food, the farming practices (e.g. agroforestry or permaculture), the conversion of forests to agricultural land and vice versa, the cascadic use of wood, or the effects from extreme weather.

The game theoretical model

The qualitative model already looked at different countries, whether they are rich on primary resources, developing, or already industrialized with a huge anthropogenic stock of resources that could be recycled (e.g. through urban mining) and the quantitative model examined the prospect of some regions in the world to later transform towards renewable energy. Considering that there might be winners and losers like oil exporting countries that lose their business model, or countries rich on primary resources that could later become exploited and substituted by recycled resources from other countries, or countries that are tempted to continue to use potentially cheaper remaining fossil energy while the resources to implement renewables become scarcer, we chose not to decide for the WEO regions which kind of countries are present but instead developed a very small, general and descriptive model that just distinguishes two kinds of countries: one that is rich on primary resources but yet developing and one industrialized with a growing stock of anthropogenic resources. The model allows to explore the potential shifts of value creation as well as the effects of resource efficiency in the industrialized country on the use of the remaining resources by the developing country.

First results

The project has just started to define scenarios and collect the results and conclusions. For the International System Dynamics Conference 2021 we have selected first results to show the potentials of the different modeling approaches.

Results from the Qualitative ICARE Model

The qualitative model revealed just a few synergies between resource and climate policies. For example, a change of consumption patterns could serve both targets. And any need for more energy requires more resources for renewable energy as any need for resources requires more energy.

Trade-offs are, for example, the use of biotic resources if they require the conversion of forests to agricultural land, or numerous so called rebound effects for example if more use of renewable energy decreases the price for fossil energy, if longer product life cycles lead to fewer innovations, or if the scarcity of crucial materials for renewables prevents poorer countries from their transition, or if resource efficiency decreases the price for resources so less efficient countries will use them anyway.

Figure 2 shows an example of a tornado chart of the Insight Matrix of just one of several targets. In order to draw conclusions from a qualitative model one compares the Insight Matrices of different factors to see which factors have a positive effect on different targets and which factors have contradicting effects. Those effects can change from short- to medium- to long-term. A closer look at differentiated weightings along the cause and use chains or at the reinforcing or balancing feedback loops helps to explain the results. The Insight Matrix processes the effect of all the feedback loops. Nevertheless, to pick the decisive feedback loops from the more than 15 million of the qualitative model still requires the experience of an expert.

Results from the Quantitative ICARE Model

The base scenario of the Quantitative ICARE Model shows that the current paths by no means lead to 100 percent renewable energies by 2050. Only a massive acceleration of a net installation of renewable energies and the electrification of mobility, housing and industry could lead to greenhouse gas neutrality of the energy sector by 2050, theoretically for every part in the world, as figure 5 shows.

Effects on raw materials

Figure 6 shows the pattern of the need for resources in that case for copper that is needed for infrastructure and electric cars. After a decline of high-grade primary resources more expensive low-grade resources will be used followed by recycled copper depending on the design for recycling of the installations and the organization of the recycling. Without proper recycling the world would run out of copper before a second life cycle of the renewable energy installations. For silver it is already foreseeable that we will run out of it and that we need to utilize the existing alternatives for substitution within photovoltaics.

However, the steep increase of demand for the resource needs to be seen critically. Capacities for mining, transportation and processing and later for recycling need to be raised for a relatively short period of time. The microeconomics and following that the prices could create their own dynamics that could hinder the quick transition towards renewables. The peaks of the demand will even increase if countries continue to postpone their efforts announcing that they would later accelerate the implementation. Therefore, not just for the accumulated total of greenhouse gas emissions but also for the availability of resources and profit from the lower price of high-grade primary resources it would make perfect sense to massively increase the implementation of renewables right now to get a more or less steady demand for resources that could meet reasonable business models for suppliers.

That pattern, of course, reminds us system modelers of Peter Senge's description of an archetype of "Shifting the burden" (Senge, 2006).

The case of synthetic fuels

A variant, "Shifting the burden to the intervenor" can be shown with the tendency to lower a country's ambitions to implement renewable energy in favor for imports of synthetic fuels from power-to-gas/liquid from other regions. Not only is there the risk that those exports from those countries lead to more use of fossil fuels for their own needs, but also would the inefficient conversion require more overall renewable energy implementations. After all, we need the power-to-liquid/gas for sea going ships, long-haul planes, industrial processes and the aforementioned electrolysis to provide energy in longer periods of neither sunshine nor wind.

The need for material efficiency

On the contrary, for the expected extreme patterns in its need for crucial materials the transition towards renewables heavily depends on the overall need for energy and thus also the package of material efficiency scenarios as defined with the WEO 2015 needs to be globally implemented. Figure 5 shows how with a full implementation of renewables assuming no further increase of energy demand in the future we will still need primary resources to add to the recycling quote below 100 percent for the repowering of renewable energies. The raw material consumption (RMC) compared to today's use of fossil resources will even increase with the shift towards renewables and only over time with an increase of recycling materials in a phase of circular economy it will be way smaller.

The economical aspects

The macroeconomics behind this global transition are also important. Figure 7 shows how for example for Europe the price for energy will continue to rise while the macroeconomic effect because of the value creation from the implementation of renewables compared to the import of fossil fuels will increase – thus the negative values of costs. However, a region like the middle east faces an increase of costs unless it uses its existing infrastructure to export synthetic fuels from a regional surplus of renewables.

North America on the other hand could face an up and down depending on its share on the value creation from renewables. Globally, the transformation seems to be a systemic source compared to the systemic sink that the combustion of fossil fuels means.

Some countries or players may even consider waiting with their transformation until the technology has improved and until there are inexpensive recycled materials available. Like the game theoretical prisoner dilemma (Poundstone, 1992) shows only few players could choose to do so.

The role of biotic resources

Not only do some areas expect to energetically use biomass but also as mentioned before we have to look at the potentials for a substitution of abiotic resources by biotic resources as well as at the effects from carbon sinks, etc.

The LULUCF module of the Quantitative ICARE Model shows with its basis scenario (figure 8) that the current trajectory of a global increase of population with an increase of consumption of animal food would lead to huge deficits in food supply that could probably lead to more deforestation. However, the model therefore explored the range of possible scenarios from changes of consumption pattern like less consumption of animal products and less waste of food, combined with the utilization of parts of the arable but yet only extensively used areas. Numerous realistic scenarios could lead to a surplus of biotic resources that could imply either more afforestation, more organic food, or in the least productive case more biogas.

Results from the game theoretical model

The simulations (figure 9) from the last model out of the ICARE model family show how inevitably any future economic development leads to some form of crash. A crash of the economies in “both parts of the world” becomes likely if the global economy will continue to grow. There are two explanations for this: 1. Without widening the system boundary to think of asteroid mining etc. there will at some point be a depletion of resources with no substitutes or room for efficiency gains left and with no 100 percent recycling. 2. Even if there was a 100 percent recycling it still can only provide for the amount of resources that was used in the past, the average life span of the products before present.

The current economic system at least for developing and emerging countries relies on investments into future potentials. Once there is a contraction it would be reinforcing even if the prices for primary resource for those countries would rise.

Without international political intervention it also seems likely that some industrialized countries keep their hand on value creation while other countries remain restricted to their role of being exploited for the primary resources and being left for nothing once there is the need to shift to the use of secondary materials in a circular economy. For a piling of resources in the anthropogenic stock it could even appear smart to not be resource efficient until there are no high-grade primary resources available anymore.

However, if we continue to decouple material use from economic growth and provide for increased value creation in developing countries as well both parts of the world could end in a scenario with moderate peaks of wealth but with also moderate decreases of material wealth and even a higher accumulated total of material wealth because of the dynamics of the financial world and the growth of the service economy.

The future needs to be shaped

The ICARE project will result in further publications with more background information and comprehensive documentation of the models. The aim of this paper is to briefly present the combination of different models and the application of different modeling concepts – from descriptive and explorative modeling, from qualitative and quantitative modeling, and from system dynamics and process modeling.

The results show that a global transition towards renewable energy is possible but currently not likely. They also show how crucial resource efficiency with all the political instruments that lead to a design for recycling, cascadic use of biotic resources, etc. is.

It also revealed the role of economic aspects whether it is the actual macroeconomic benefit of a transition despite rising energy prices, the questions of value creation, or the change of prices for resources with their shift from high-grade to low-grade to recycled and the possible implications for the transformation towards renewables in parts of the world.

After all each country should start as early as possible while also seeking to save energy and resources even if some other countries could profit from shrinking prices. On the contrary, in the not too long run richer countries need to support developing countries to finance the energy transition and also to provide for economic stability. With no intervention the dynamics are frightening for both the prospect of climate change and of economic and geopolitical stability.

The models will be shared with the free web based iMODELER once the project is finished and the comprehensive documentation written.

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Figures

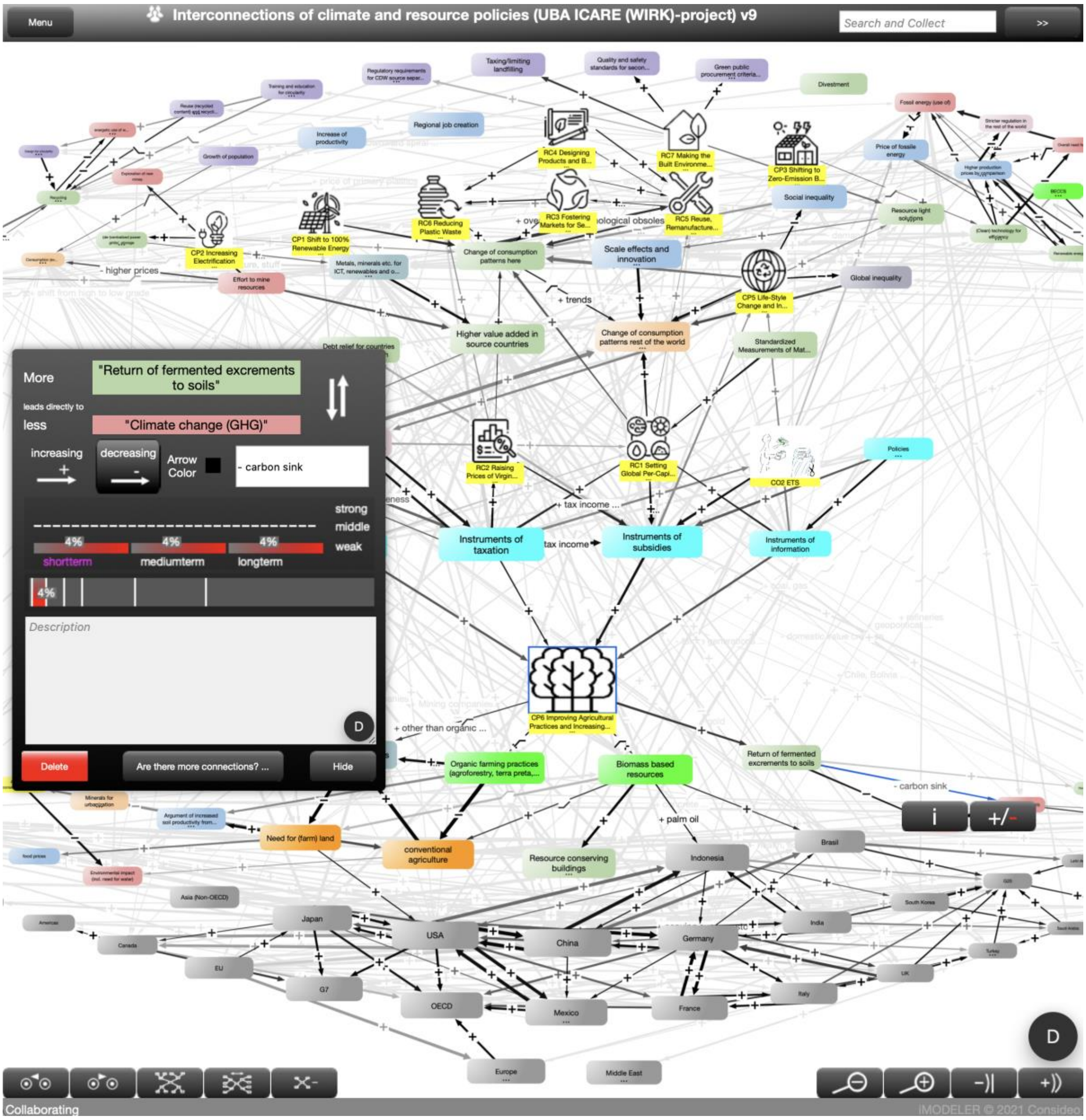


Figure 1. Screenshot from the Qualitative ICARE Model

Figure 2. Screenshot from a tornado chart of an Insight Matrix

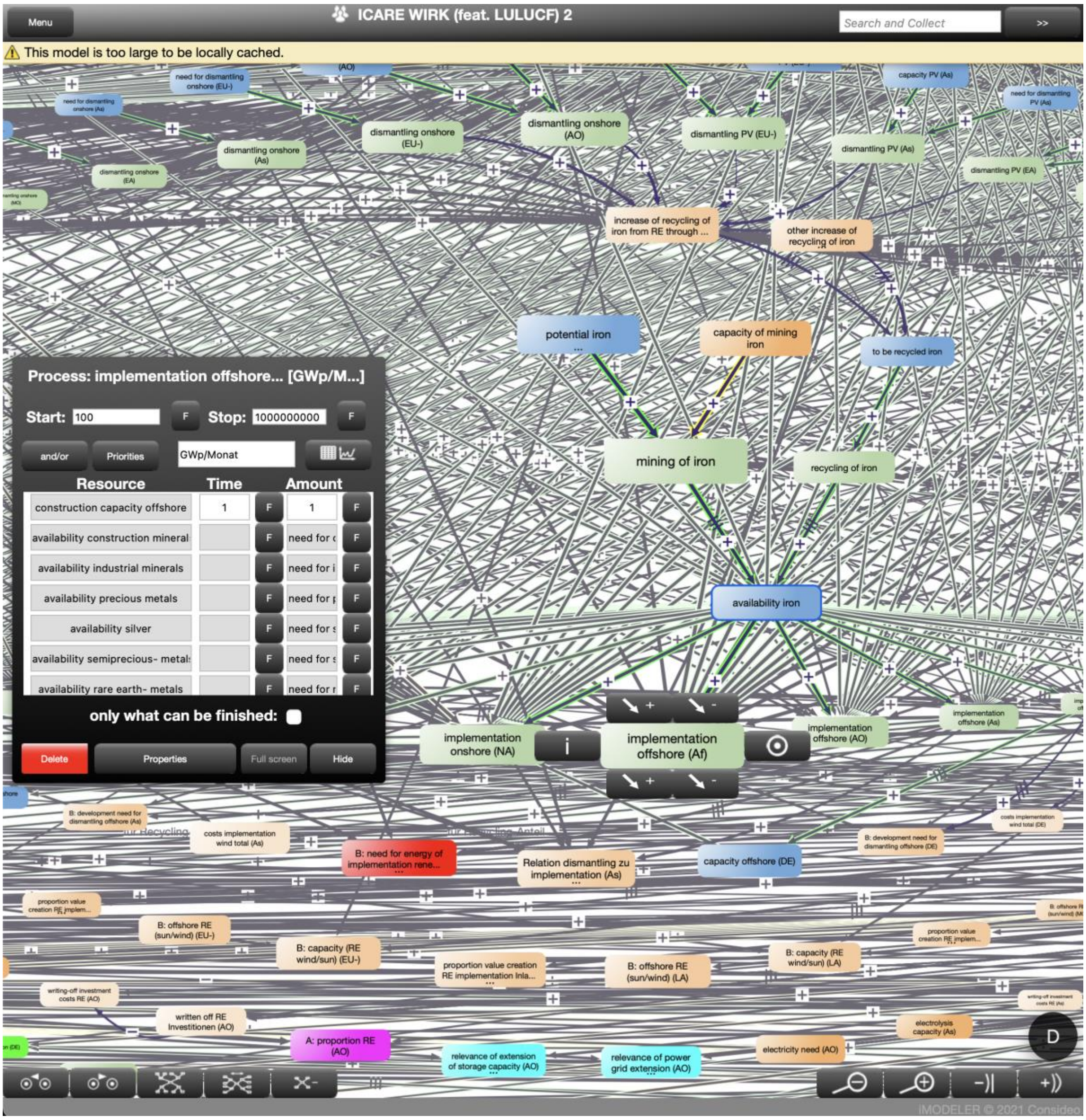


Figure 3. Screenshot from a process factor from the Quantitative ICARE Model

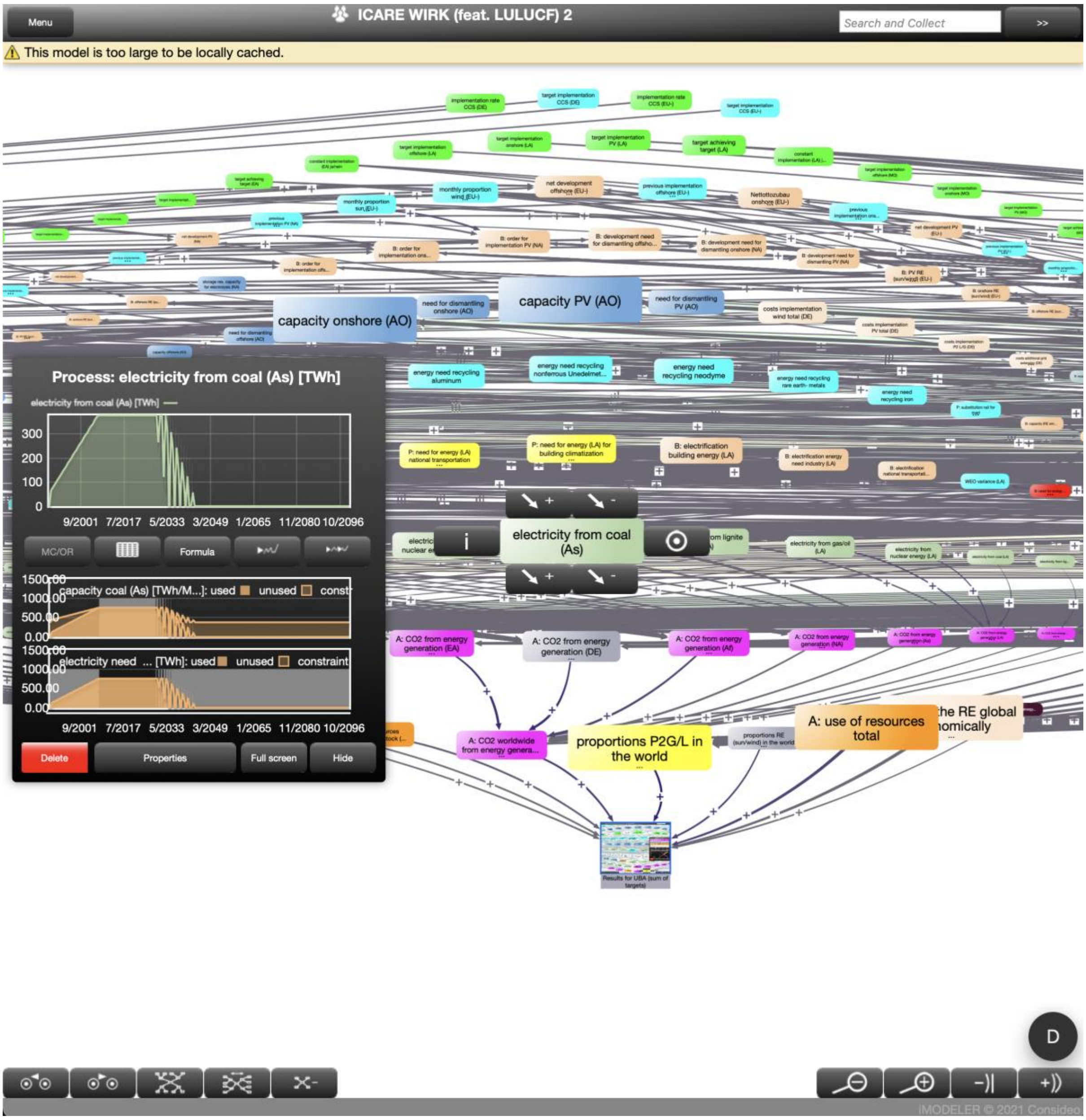
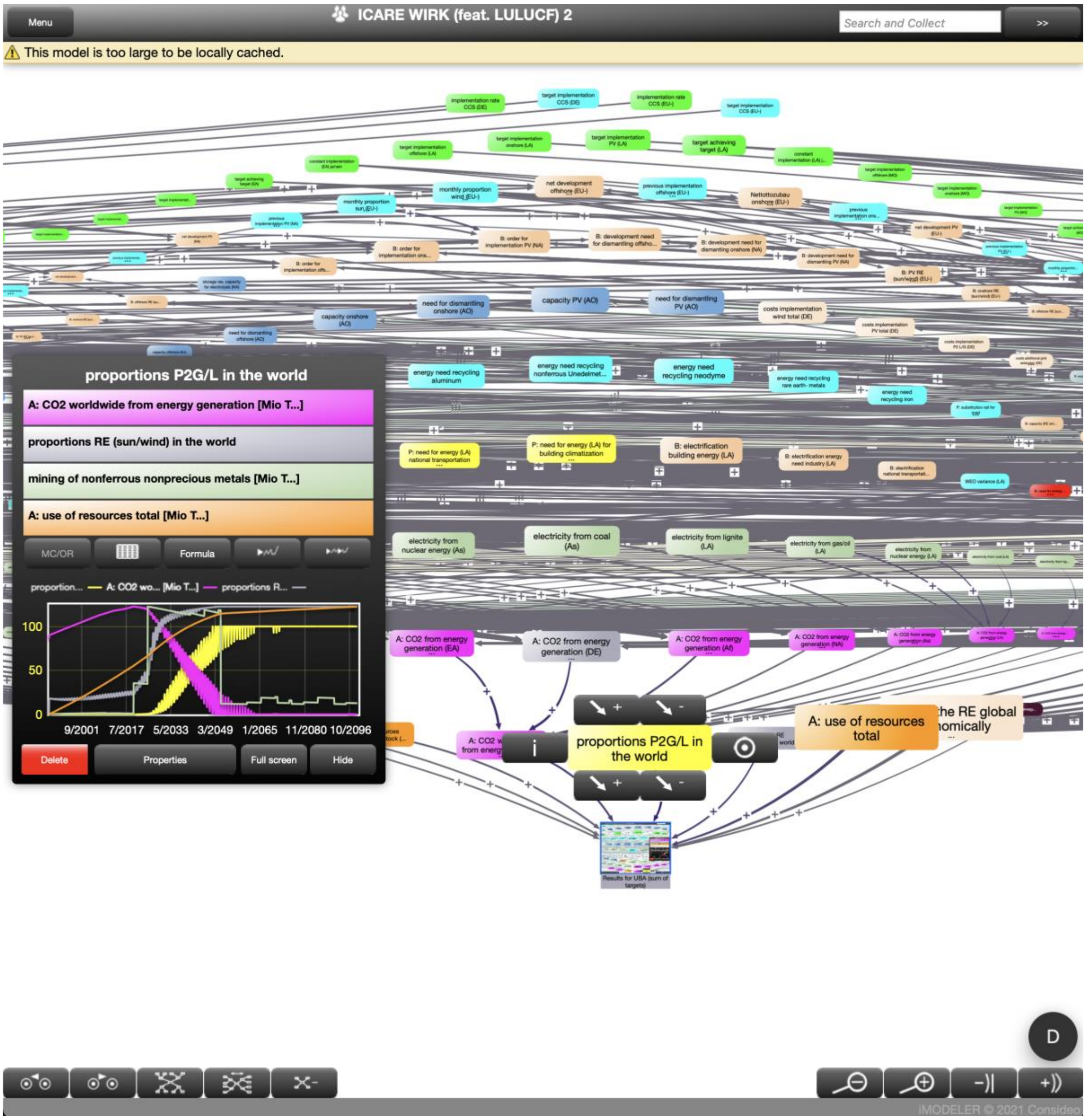


Figure 4. Screenshot showing simulation results from the Quantitative ICARE Model



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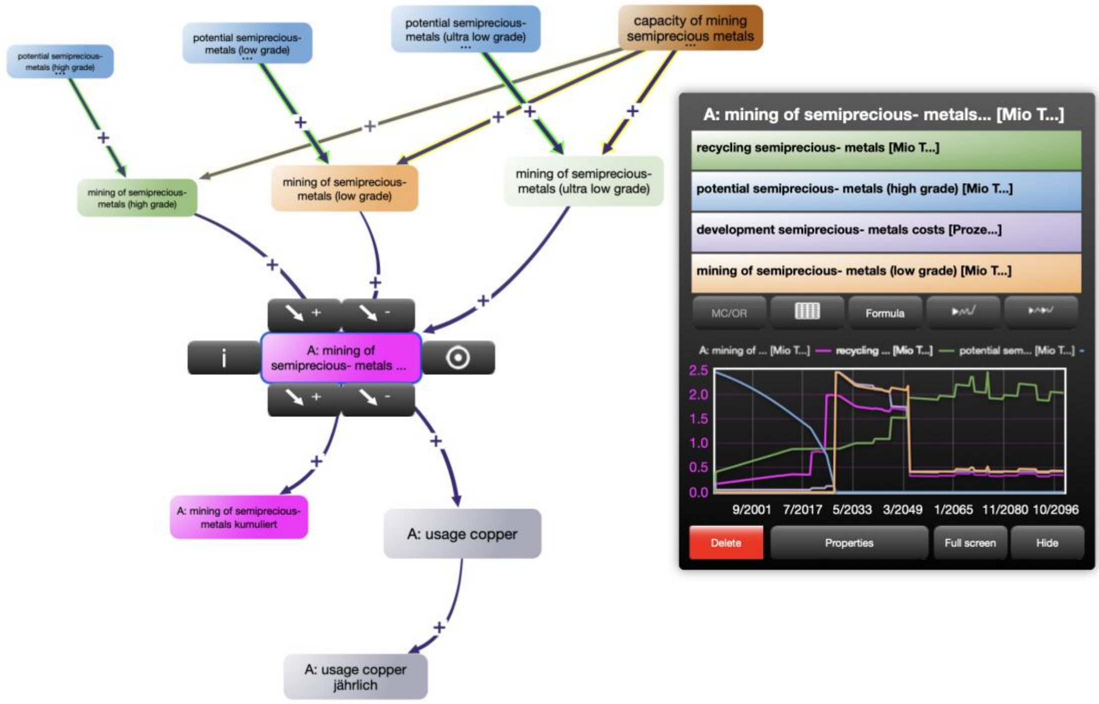
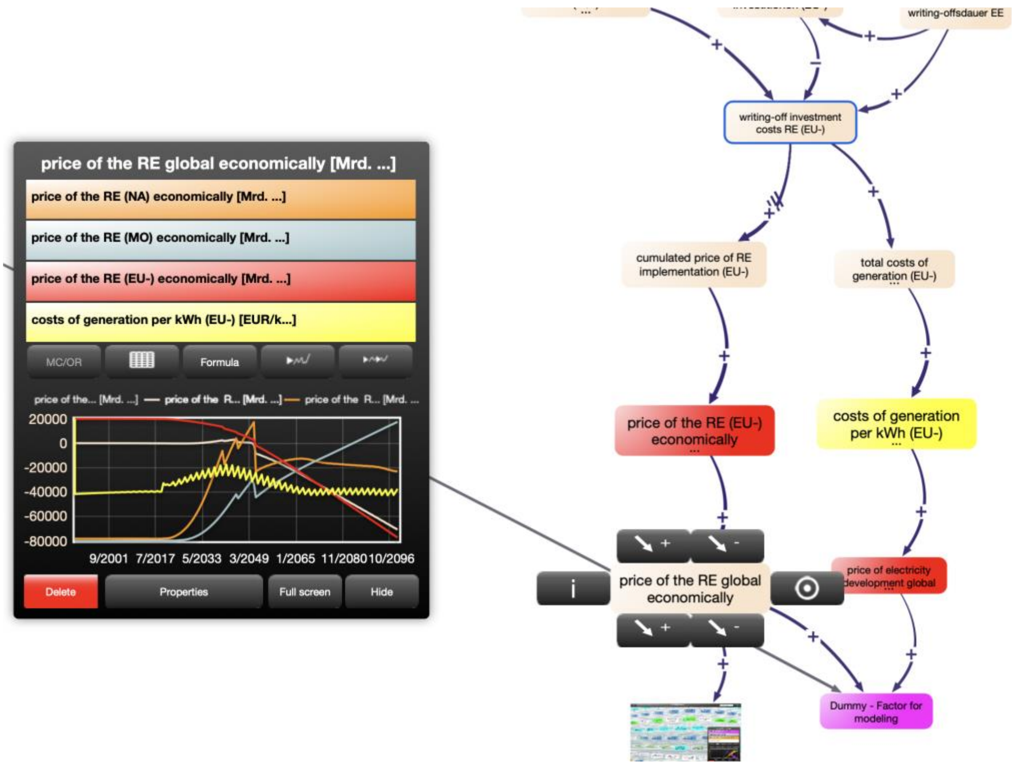


Figure 6. Screenshot showing simulation results from the Quantitative ICARE Model



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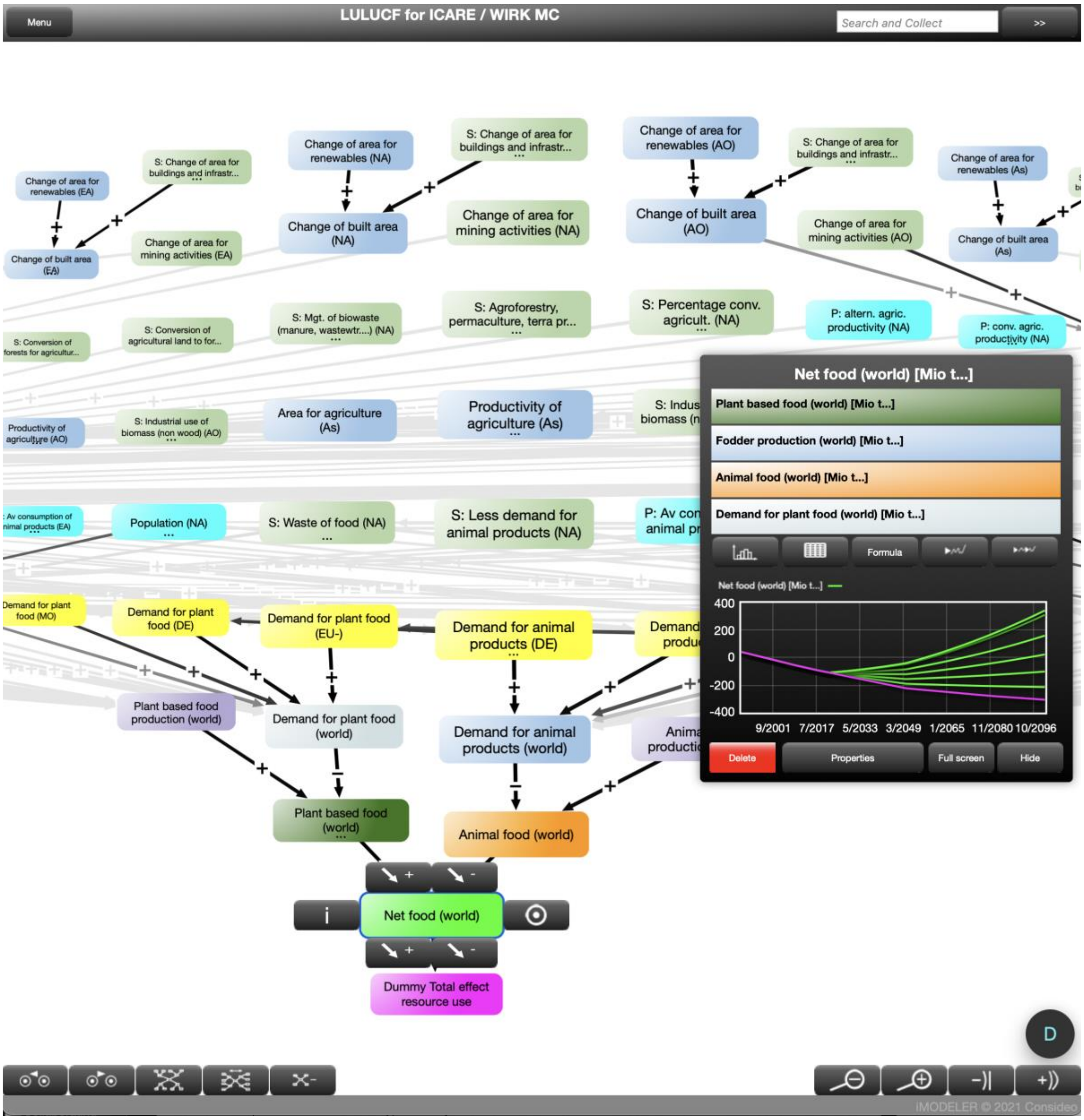

Figure 8. Screenshot showing simulation results from the Quantitative ICARE Model

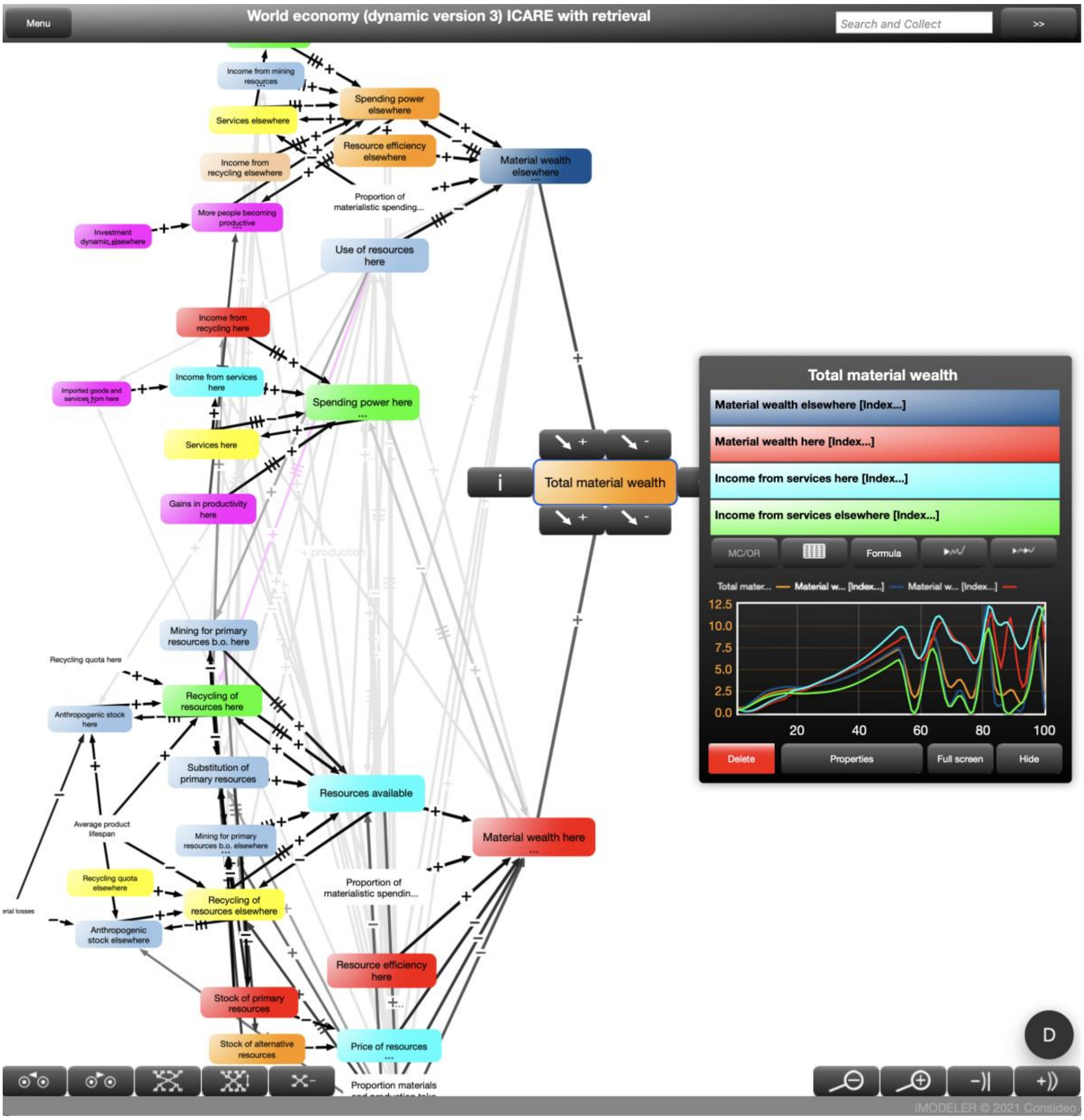

Figure 9. Screenshot showing simulation results from the Quantitative ICARE Model