The ToC and the Global Energy Transition

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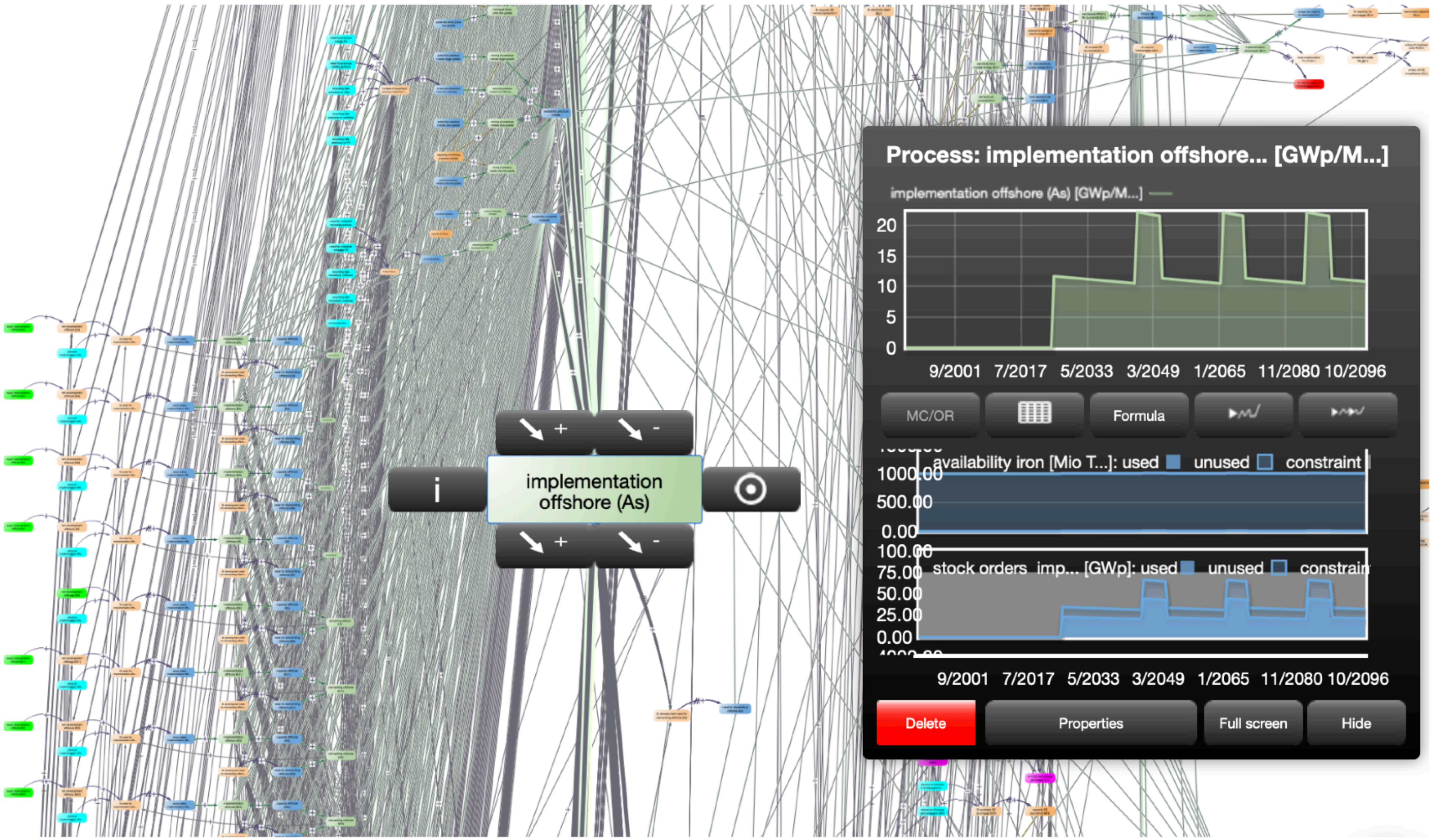


Process-Factor out of the ICARE Energy Model indicating that for offshore wind power in Asia in the selected scenario apparently the orders are the limiting factor (constraint, indicated by grey background) while the capacities and resources seem to be available.

CONSIDEO

ToC and renewable energy

THE THEORY OF CONSTRAINTS AND THE GLOBAL ENERGY TRANSITION

Summary

Onshore-Wind Power -we have only built a fraction of the required capacity and already acceptance by the population could be the bottleneck.

After we had already investigated the global transformation towards renewable energies with the GEE(R) model (Grey Series - Part 1: Renewable Energy - It Could Be Done), we took another look at the global energy transition with the ICARE model for the Federal Environment Agency and explored the role of resources even more.

Together with Ecologic Institute, we first qualitatively investigated the nexus between climate protection and resource conservation, and then quantitatively used simulation models to look not only at the extent to which sufficient raw materials are available for the global expansion of renewable energies, but also at the effects of resource efficiency, an increased choice of photovoltaics, the import of synthetic fuels, or the substitution of greenhouse gas intensive steel and concrete with biotic raw materials.

We will address the substantive aspects of this project first with peer-reviewed publications elsewhere and only later expand on this paper. With the gray paper here, we describe the application of the Theory of Constraints (Goldratt " The Goal") and its further findings. The iMODELER has special factors for modeling process steps and resources and already shows the potential constraints (limiting factors, bottlenecks) at certain points in time.

Other insightful aspects are the dangers of thinking of a critical path instead of a critical chain (Goldratt "Critical Chain") or a "Shifting the burden to the intervenor" archetype (Senge "The Fifth Discipline").

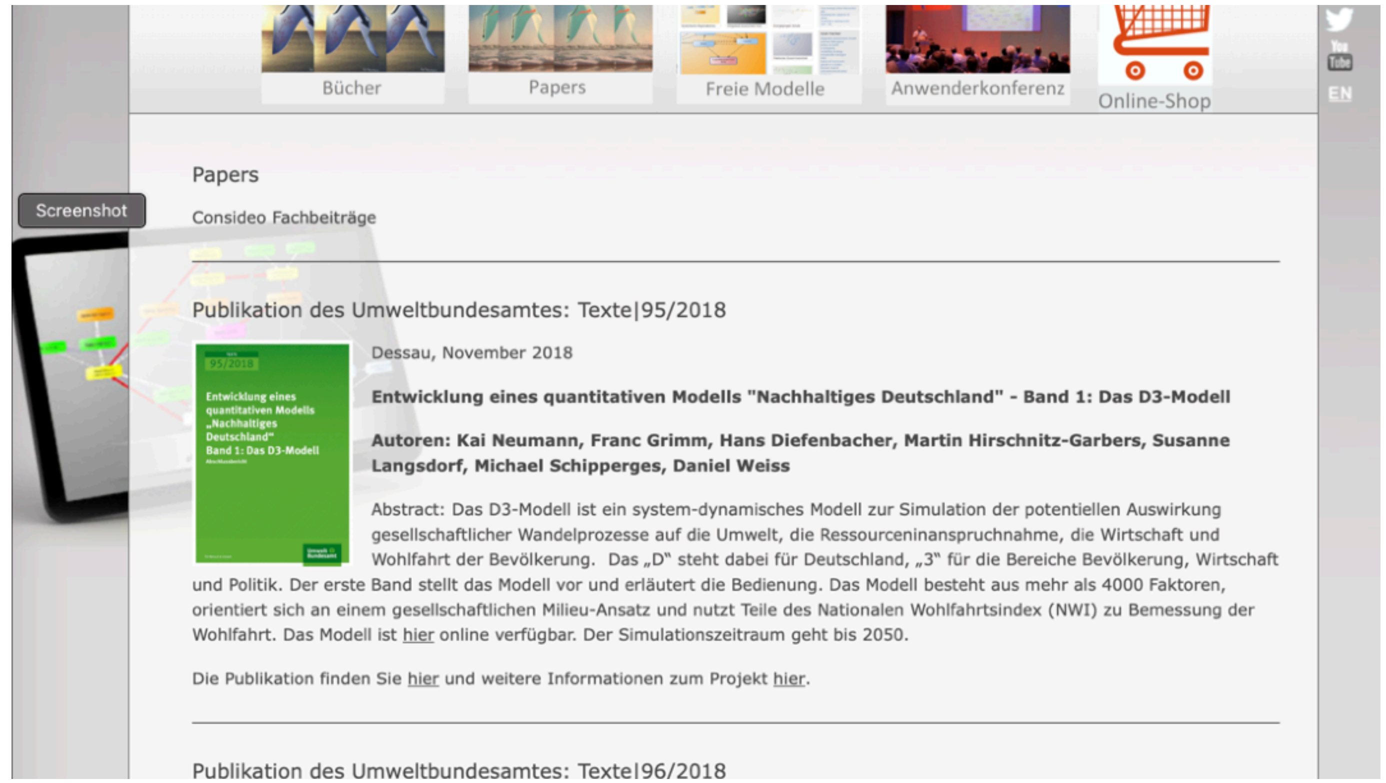
We show that late targets lead to missed targets and that energy imports of solar power or synthetic fuels that seem to make sense nationally lead to potential constraints internationally.

The grey series

Studies do not seem to reach policymakers at all, are usually too specific for the general public, and are all too often perceived as competition by other scientists or are then not taken up.

We can reach policy makers through the public, and for the scientific community we will continue to write official project reports and also peer-reviewed articles. But for the public, we want to offer an attractive readable format that gets to the heart of findings and action to be derived from them - our 'grey series' in reference to the term "grey literature."

The global energy transition requires resources, which in turn require energy. Bottlenecks may not only be raw materials, but also construction capacities or affordable prices.



Screenshot of the Consideo website with the project reports and scientific publications linked there (www.consideo.de/papers.html)

Therefore, in addition to resource efficiency, the substitution of fossil raw materials with biotic raw materials that can sequester carbon also plays a role.

This paper looks at where the potential bottlenecks may lie, to what extent these depend on the chosen paths of transformation in the world, and what conclusions we can draw from the management concepts behind the Theory of Constraint (Goldratt) or the System Archetypes (Senge).

Theory of Constraints

E.M. Goldratt's Theory of Constraints (ToC) encompasses the realization that every process has a constraint/ bottleneck at every point in time and that only fixing it leads to an improvement of the overall process. Improving processes elsewhere (the quantity) leads to waste or preventable cost since targeting constraints usually means adding resources..

Critical chain vs. critical path

In addition, Goldratt points out with the concept of the critical chain as an alternative to the critical path that in the critical path each process step is given a buffer time, whereas in the critical chain each process step starts as early as possible and the buffer times of the individual process steps are added up at the end. In this way, process steps are not started as late as possible only to be delayed by unforeseeable disturbances, which then delays the entire process.

The global process

From this point of view, the global energy transition is one of the largest overall processes of mankind - ultimately, because we apparently do not even understand the comparably important global provision of impulses as a process. In the expansion of renewable energies, the constraints can be the provision of raw materials, construction capacities, grid expansion, or storage facilities to balance the fluctuating supply of renewable energies.

This consideration becomes complex when the causes of any constraints have their own dynamics. For example, the supply of both feedstock and construction capacity depends on whether the business models behind them are worthwhile, i.e., whether demand will last long enough for companies to invest, especially at the end of the 100 percent renewables target. If, on the other hand, demand is short-lived, the investment will not be worthwhile until the price is sufficiently high, which could tempt some regions to at least further postpone expansion.

Another effect on the price is the depletion of so-called high-grade raw material deposits, such as copper, after which more expensive low-grade deposits are needed. Potential economic constraints are then created.

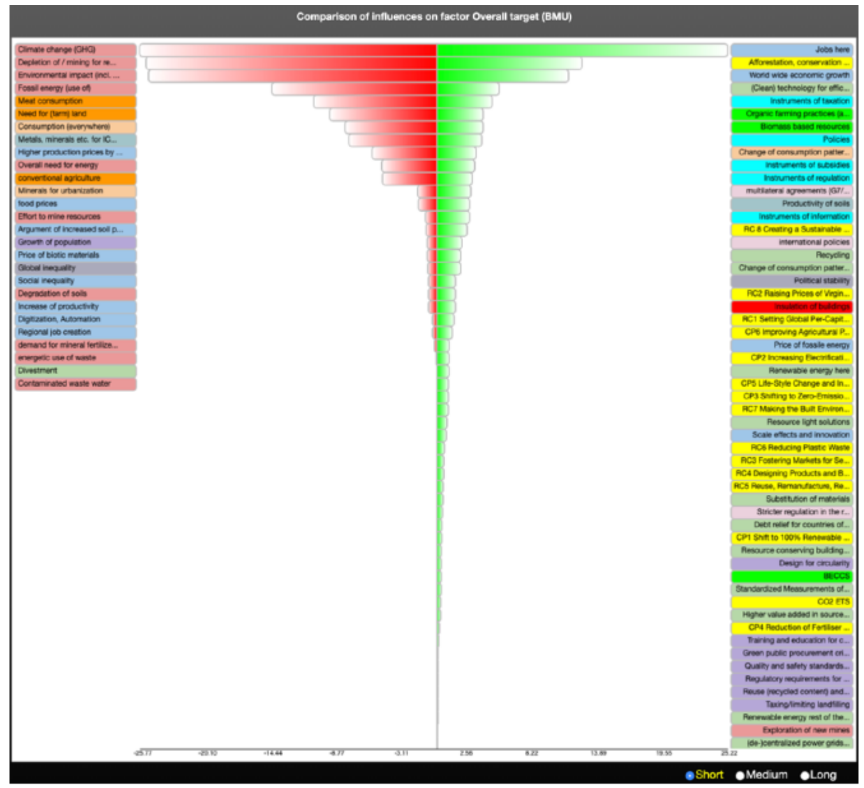
The ICARE models

We have developed 4 models as part of the project:

- the Qualitative ICARE Model
- the quantitative ICARE Energy Model
- the quantitative ICARE LULUCF Model
- the quantitative ICARE Game-theoretical Model

The Qualitative ICARE Model

The qualitative cause-and-effect model contextualized knowledge from the literature and international expert interviews around the nexus of resource conservation and climate change mitigation. Potential winners and losers of the global energy transition, the importance of recycling and the shift of value creation from resource producing to



Tornado view of the Insight Matrix

recycling nations, the potential role of biotic raw materials, the price increase of raw materials, the inertia of fossil industries, etc. could be explored in their potential impact.

Even after weighting, the qualitative model 'only' shows what potentially has more effect than something else. But whether the raw materials are really sufficient, whether there is a potential for biotic raw materials, and which constraints might arise when over time, we could only explore with quantitative simulation models.

The ICARE Energy Model

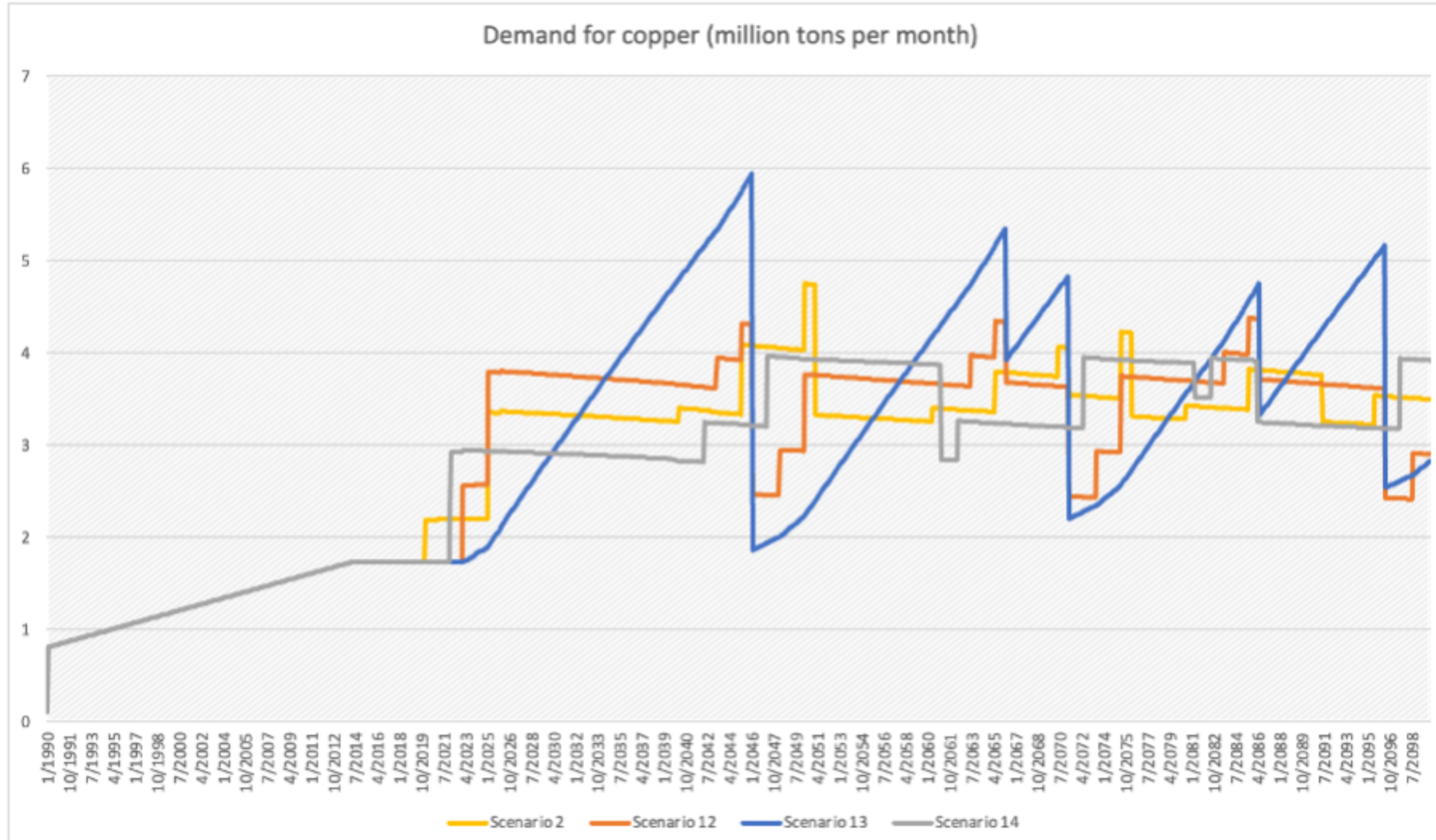
The very large model is the extension of the GEE(R) model. It includes the world regions according to the International Energy Agency's World Energy Outlook (WEO) 2015 and picks up their forecast of the future development of the energy demands of the respective sectors (transport, industry, buildings, ...). It considers the global expansion of onshore/ offshore wind power, PV, power-to-liquid/gas (P2L/G) and its feedstock and capacity needs.

High grade and low grade feedstock deposits were distinguished, recycling and repowering were built in as processes, as well as reverse powering of surpluses converted to P2L/G depending on capacities, with a global market for P2L/G as well.

The model is very close to reality at its aggregation level, and we ran over 10 scenarios - with different expansion paths (start when, reach 100% target between 2045 and 2060, constant high or increased backward expansion rate, focus on wind or PV, electrify sectors as much as possible, or use P2L/G) and with different assumptions on demand (sufficiency, use of biotic feedstocks).

The path is decisive

We have assumed only today's known reserves of feedstocks as a limiting factor in the models. The



The courses of demand for capacities for the respective scenarios

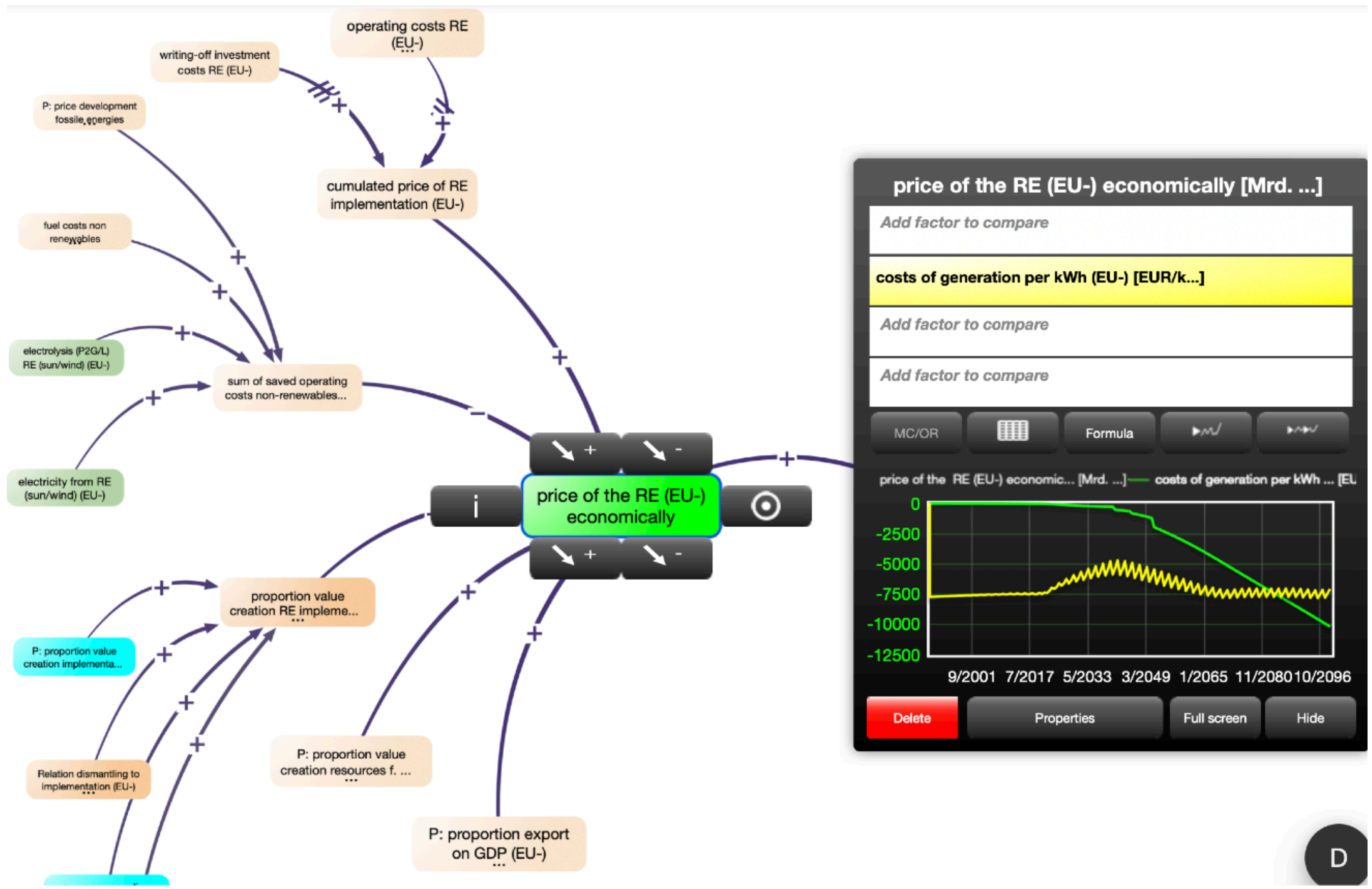
construction and mining capacities as well as the recycling and transport capacities were first set arbitrarily high. Thereupon, depending on the path, some extreme demands for capacities result for the respective scenarios, both in the amount and in the then foreseeable decrease in demand when waiting for repowering of installed renewable energies.

While high-grade deposits, for example of copper, will already be exhausted in a few years, so-called low-grade raw material deposits will be available for the expansion of renewable energies until beyond the year 2100 - provided that they are recycled as far as possible.

It’s the economy, ...

This has economic implications above all. Regions starting the expansion many times over will be able to fill their anthropogenic stockpiles with high-grade raw materials at moderate prices and later draw on them with high added value. Regions starting later, on the other hand, could then resign themselves to high raw material prices.

Overall, the energy transition is an economic success model for most regions - with the exception of countries that export massive amounts of oil and gas. Although energy prices are rising, domestic value creation is being massively increased, so it will be a matter of clever redistribution to compensate for the increased energy costs.



Energy prices in Europe will rise for the time being, but economically compared to fossil fuels, the energy transition is a clear gain due to increased value creation.

If the regions start later, it results in more greenhouse gas emissions than if they take longer to build out later. So increasing the expansion rate only backwards is not only an economic risk, but also an environmental one.

Shifting the burden ....

So without a massive start to global expansion, we will see extremes of capacity demand or simply fail because of it. Against this background, the tendencies to rely increasingly on P2L/G must be viewed very critically. Using P2L/G beyond the extent we need it for reverse power generation in so-called dark slack periods or for direct use in industry or for synthetic fuels for long-distance flights and maritime shipping as well as a base material for the chemical industry, also in areas that can also be electrified (e.g. building heat with heat pumps or transport with batteries), means in the end an even further increased demand for renewable energies and corresponding resources due to the conversion losses.

The drivers behind the idea to rely more on P2L/G range from parts of the automotive industry to the gas lobby (pipelines, heating, etc.) to citizens who would rather import fuels than see more wind turbines in the landscape or have to change anything at all.

The question of sense is not so easy to answer. Photovoltaics are currently extremely inexpensive per kilowatt hour generated. If, in addition, PV plants in sunny regions (such as Africa or the Arab countries) are operated with a high yield, then the efficiency losses in the conversion to P2L/G and through transport could supposedly be compensated.

However, the ICARE Energy Model has shown in a scenario that the doubling of PV shares (measured by the mix with wind based on the UBA RESCUE study) in power generation still seems reasonable, since the generated P2L/G quantities are needed anyway, but that beyond that a reduced electrification of the sectors would ultimately bring with it massively more expansion of renewable energy and significantly increased the probability of bottlenecks in the capacities.

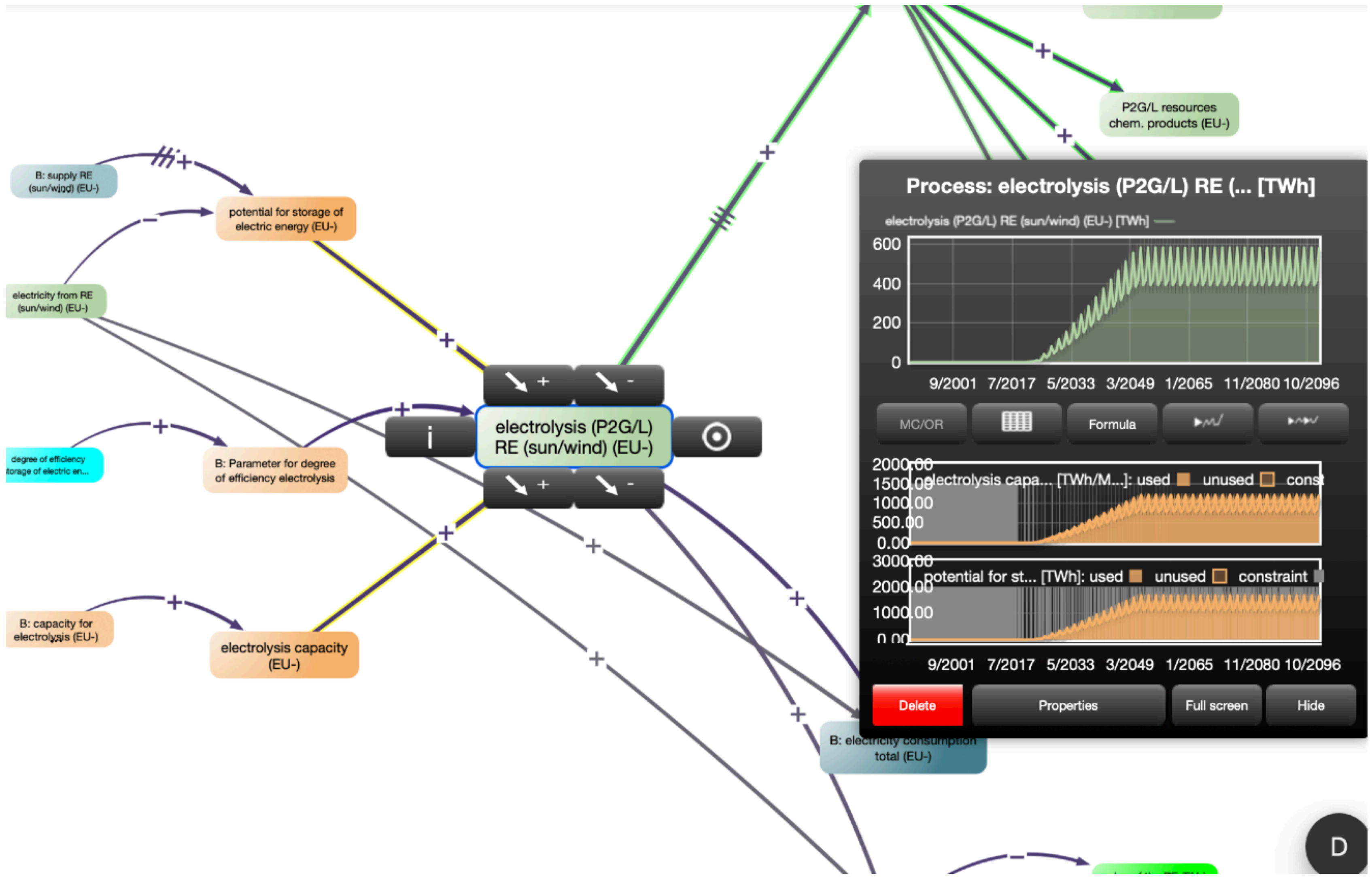
Shifting the burden of expansion too much onto sunny foreign countries therefore made little sense.

Under-utilized Electrolysers

Another aspect, however, is the question of the utilization of the electrolysers. Technically, it makes sense to use them only to convert surplus renewable energy into P2G (green hydrogen). Economically, however, such plants and the entire logistics behind them want to be utilized to capacity. Therefore, it is often argued that natural gas can also be used to produce so-called blue hydrogen, even with the argument that this would then provide a carbon source for synthetic fuels.

Technically and economically, such arguments seem plausible, but in the big picture, this will ultimately require more renewable energies and generate path dependencies if infrastructures and demand for blue hydrogen are built up.

Scaled up for all regions, the additional demand for renewable energies would be massive.

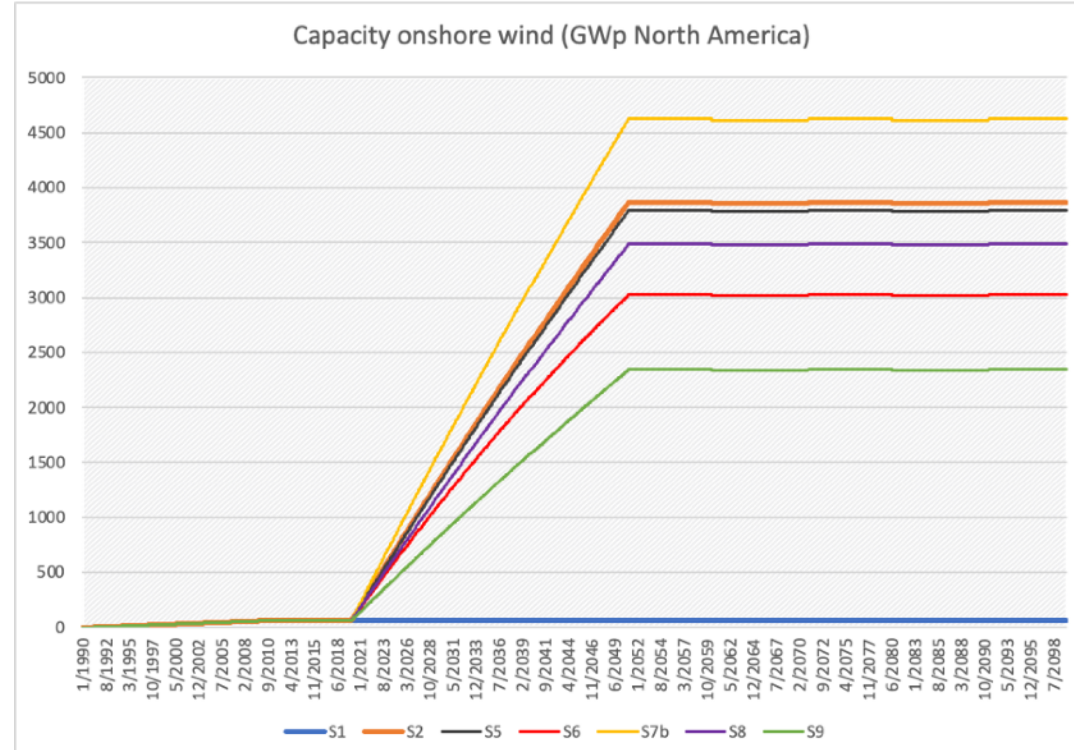


Electrolysers are needed when there is a lot of sun and or wind - and during dark periods or lack of surpluses they remain under-utilized (gray background means constraint, i.e. lack of capacity or lack of surpluses).

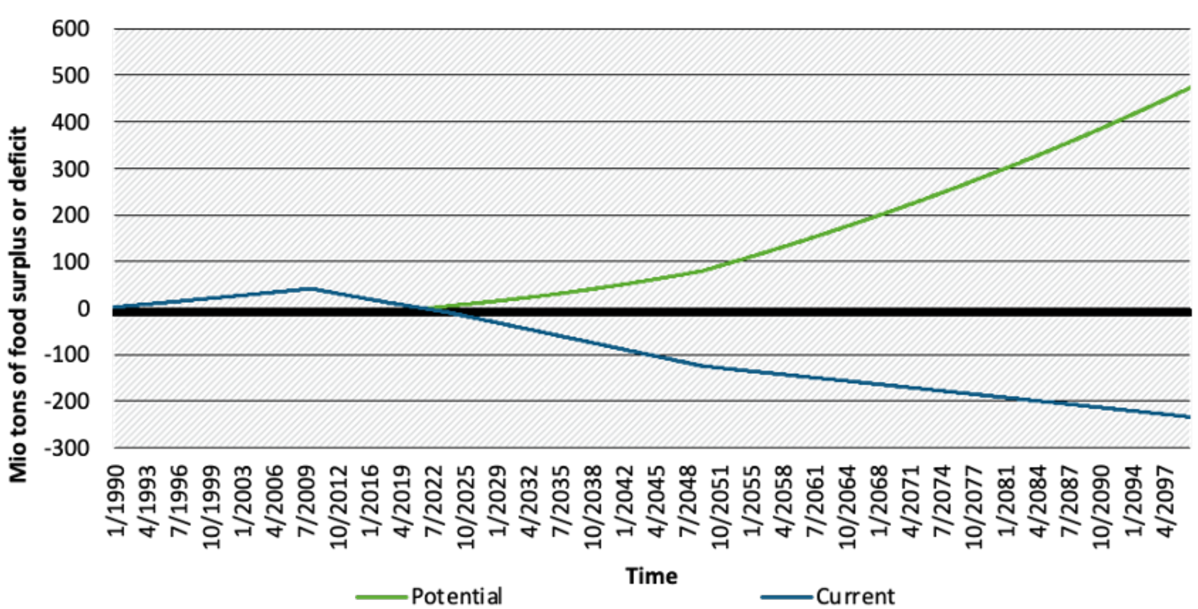
In the ICARE project, we have therefore looked at how energy can also be saved through raw material efficiency and substitution of greenhouse gas intensive raw materials such as steel and concrete with biotic raw materials.

The ICARE LULUCF Model

To explore the material and energetic potential of biotic raw materials, we have developed a global LULUCF (Land Use and Land Use Change and Forestry) model, again as a process model, which looks at the availability of resources (land, fertilizer, ...). It is based on FAO data, includes food, agriculture, forest, etc. and shows that even without crop losses due to climate change, we will soon no longer be able to feed the world without cutting down forests. But if we, on the other hand, start a nutritional turnaround etc. (see figure), we even have a potential for additional forest areas and a use of biotic raw materials (instead of e.g. steel and concrete) in cascades, which would then reduce the need for renewable energies overall.



North America representative for all regions: S2 the UBA Scenario, S5 material efficiency, S6 30% sufficiency S7b more P2L/G/less electrification, S8 biotic feedstocks, S9 more PV but without significance since only wind is looked at here.

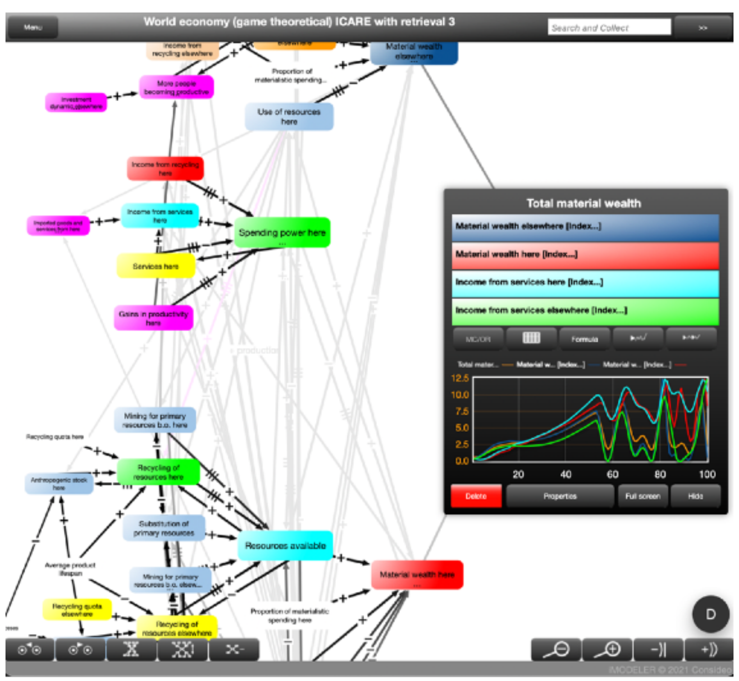


Blue shows theoretical food surpluses/deficiencies with current land use and dietary patterns; green shows the potential with halving consumption of animal products, halving food waste, and doubling the use of unused land.

ICARE Game-Theoretical Model

The game-theoretical model showed on a very abstract level how material growth must logically lead to disruptions if, with the exhaustion of key raw materials, recycling can only fall back on the level of what was used a lifetime ago - corrected for any further increases in efficiency.

A further aspect was the voluntary transfer of value creation to developing countries, as this is the only way to ensure economic growth into the future. In the energy turnaround to be planned globally, political measures must therefore intervene in the market both nationally (e.g. for under-utilized electrolysers) and internationally (to compensate for an increase in the price of raw materials and to transfer value added).



Logical collapses of the economy with global economic growth

It is doable

The global energy transition is feasible and we are already in the middle of it. However, we have to reach a "Crossing the Chasm" before a "Tipping Point" occurs, driven by "competitive altruism" of politics, economy and society. We have published our own grey papers on this.

At the same time there are the counter forces from the gas industry, the subsidized nuclear energy (is not renewable and not controllable it does not help the renewables), from autocratic governments, and by already today strongly rising raw material prices. Therefore, this process must be accompanied by the state and cannot be left to market forces.But how is the state supposed to finance the increasingly expensive energy transition at some point when the public sector is burdened with repairing storm damage.

Industry and politics can use these models to identify potential bottlenecks in resources for the provision of renewable energies if the foreseeable feasible capacities are entered into the model for certain groups of raw materials.

Digression: KNOW-WHY

The meta-systemic KNOW-WHY Thinking concludes that everything must ultimately be integrated - adapted to the framework conditions - and evolving - in competition or with change. Without integration with too much further development, something is just as doomed to fail as with too little further development and only integration.

The ICARE project looks at further development integrated by the assumptions of the WEO that ultimately developing countries will want to equal the material standard of living of rich nations. Only one scenario assumes sufficiency, 30% less of everything.

As a result, though, the project shows that integration might be missing, that capacities for the transformation of energy systems might not be available (at affordable prices), that usable land will not be sufficient, that politics does not shape the market or that the market does not initiate moonshot projects on its own.

If this quantitative growth cannot be integrated now, how can we change when today lifestyles are integrated by economic actors, materialistic values of society and mindsets of science and politics?

Change from the basis of society, the resilience movements that put doing and the value of sustainability before having, offers an opportunity.

Idealized System Design

But also conceivable is a 'designed' future. The method of idealized system design asks, without feasibility limitations, what an ideal future for us humans would look like. From this, it is then systematically concluded what is feasible today.

The future would be completely different from the self-dynamic continuation of war, injustice, pollution, and far too much work. Not doing what is feasible, but what makes sense. Already today many things are conceivable: Completely ecological agriculture with more legumes, universal basic income, renunciation of plastic and car ownership, decentralized 3D printing, and much more - without the need for people to renounce feelings of integration and further development also through possessions.

... to be continued ...

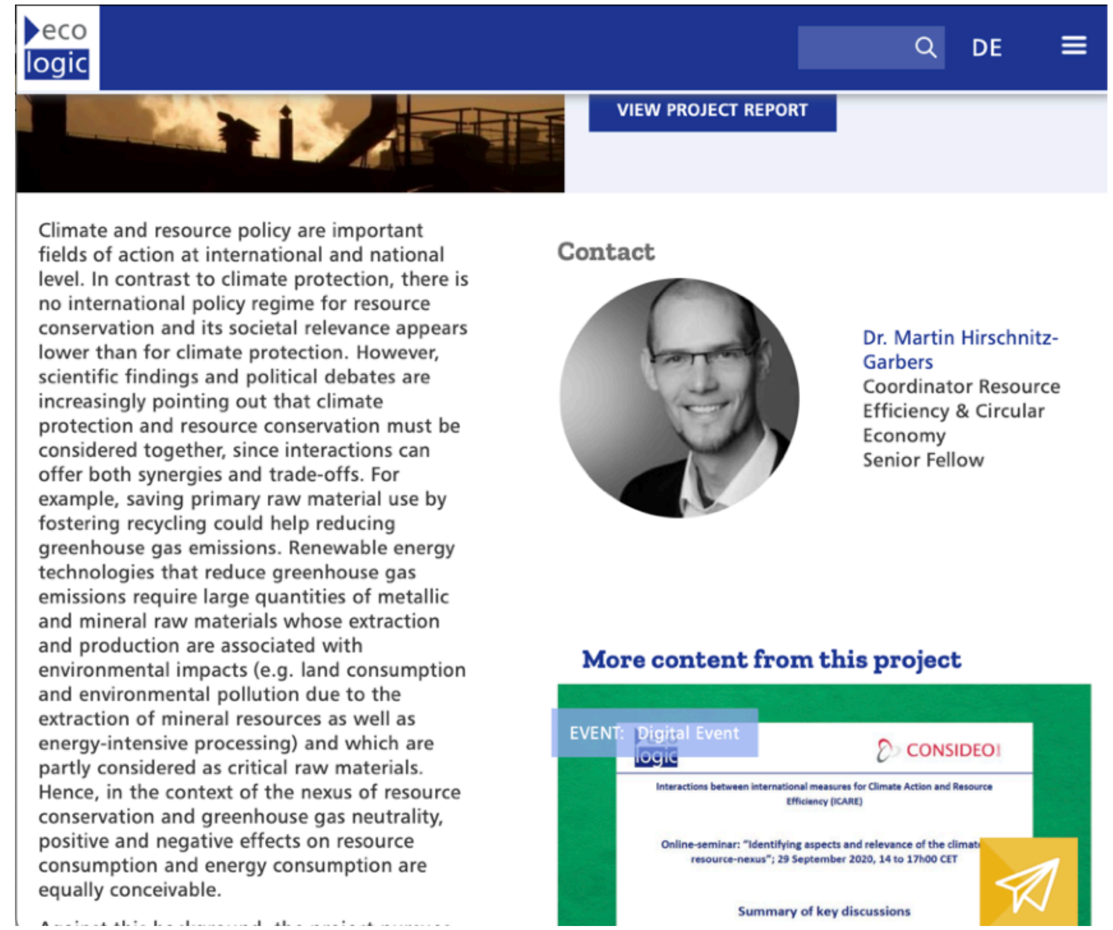
References and links

This work has been presented on different conferences, e.g. the International System Dynamics Conference 2021 or the SDEWES 2021. Here's a link to the paper: https://www.dropbox.com/s/5pb8fgvhteqh2vq/JSDEWES_1123_rev_M_v7_1661504294.pdf?dl=0

Link to the ISDC Paper: https://proceedings.systemdynamics.org/2021/papers/P1183.pdf

Here's link to the project website from Ecologic Institute: https://www.ecologic.eu/16062

Link to KNOW-WHY-Thinking: www.know-why.com



About Consideo

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Consideo has the vision of a better world. The mission is to help people understand how things are interconnected. We work with the award winning software iMODELER for business, research, politics and private individuals.

With the platform KNOW-WHY.NET we offer collective interconnections.

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