Fact sheet #1/6: Exploring the climate and resource nexus with the ICARE models

To explore major aspects of the nexus between resource efficiency and climate protection quantitatively the ICARE project developed three simulation models:

1. The ICARE Energy Model on renewable energy – a process model (based on system dynamics) on the global transition towards renewable energy, including the substitution of fossil raw materials as feedstock[1].
2. The ICARE LULUCF Model – a global land use and land use change and forestry (LULUCF) model to simulate the area of agriculture that is needed to provide food for humankind in the future and to see under what conditions additional production of biotic raw materials from agriculture and forestry for material and energetic use would be possible. This model also looks at the climate protection effects of potential carbon sinks of LULUCF.
3. The ICARE game-theoretical model – a small, abstract simulation model to explore game theoretical aspects of economic growth, resource efficiency, price development and the shift of value creation between different parts of the world.

With a series of six fact sheets we present key results from our analyses: This present fact sheet introduces the models and the scenarios, while fact sheets 2 to 6 present the different modeling findings and associated conclusions.

As a system dynamics process model the ICARE Energy model allows for a closer look at the dynamics behind shifting from fossil energy carriers towards renewables with the increased need for energy storage to capture energy generation surpluses and to cover periods with no sunshine nor wind. The model distinguishes between wind power (on- and offshore) and PV assuming today's latest technology and its parameters. Each technology has a certain year's total output per installed capacity that is unequally distributed over the months of a year. To consider variations from day and night and the challenge of longer periods without sunshine or wind, the model accounts for the increased likelihood of unused electricity associated with the proportion of renewable energy nearing 100%. Therefore, the model subtracts an increasing amount of energy (surpluses) from the average energy generation values per month and transfers them into a growing capacity for P2L or P2G to store these surpluses and make them available for re-electrification for example. The global perspective also considers a global stock of power-to-liquid (P2L) or power-to-gas (P2G) that puts national claims on imports from other regions into perspective.

Also, it enables to investigate the shifts from the use of high-grade primary raw materials to low grade raw materials and later the recycling of materials. It looks at raw materials that are needed for the energy transition, e.g., iron, aluminum, nonferrous non-precious metals, neodymium, rare earth metals, semiprecious metals (mainly copper), silver, precious metals, industrial minerals, and construction minerals. For each of these groups of raw materials there is a parameter that forecasts their demand from other sectors. GHG emissions from the extraction and processing of these raw materials are accounted for using WEO data, and only additional demands from divergent renewable energy expansion are added.

The ICARE Energy model is highly aggregated to run global scenarios. It builds on the 2015 World Energy Outlook (WEO)[2], which projects the demand for energy across different sectors and for fossil raw

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[1] The chemical industry uses fossil fuels for all kinds of products including plastics. Therefore, reducing the use of plastics reduces the need for renewable energy to produce synthetic fuels from power-to-liquid/gas (in combination with a source for carbon).

[2] https://www.iea.org/reports/world-energy-outlook-2015 by the International Energy Agency

materials for the chemical industries in different world regions. While the WEO projections only stretch until 2045 our model continues to look at a steady state of demand until the year 2100 to explore potential long-term dynamics from the repowering of renewable energy installations and the recycling of materials.

Table 1: Overview of scenarios used for the modelling underlying this policy paper

Scenario number	Brief description of the main scenario characteristics
Scenario 1 (S1)	a business as usual (b.a.u.) scenario with a transition as described in the WEO 2015.
Scenario 2 (S2)	a scenario that starts in 2020 with a constant rate of net installations that reaches 100% renewable energy by 2050 in the more industrialised regions (Europe, North America, Australia/Oceania) and with a 5-year delay for the rest of the regions. Scenario 2 uses the mix of wind energy and photovoltaics and the substitution of fossil fuels and the level of electrification of the different sectors comparable to the RESCUE GreenEe scenario[3]. It assumes 15% more sufficiency in the future than the WEO 2015.
Scenario 3 (S3)	assumes the achievement of 100% renewable energy as scenario 2 but with a linear acceleration of net installations.
Scenario 4 (S4)	looks at the effects of a further delay of then 10 years in the less advanced regions from S2 while advanced regions still meet their target in 2050.
Scenario 5 (S5)	includes the assumptions of the WEO 2015 of a maximum of resource efficiency (the so called MES, material efficiency scenario) applied to the S2.
Scenario 6 (S6)	adds 20% more sufficiency to S5 by assuming less demand from all sectors.
Scenario 7a (S7a)	assumes even more electrification, for transportation 90 instead of 60% and for industry 80 instead of 60%.
Scenario 7b (S7b)	assumes less electrification of the sectors and more use synthetic fuels (power-to-liquid/gas) instead, both 40% instead of 60% in scenario 2.
Scenario 8 (S8)	looks at the potentials from more use of biotic resources available from a major shift of LULUCF according to our global LULUCF model, again based on S2.
Scenario 9 (S9)	assumes twice the capacity for photovoltaics compared to scenario 2 with the capacity for wind energy adopted accordingly.
Scenario 11 (S11)	looks at the effects of a reduced recycling rate of 60% compared to 90% in S2
Scenario 12 (S12)	assumes that the world will start in 2023 to massively increase the capacity of renewable energy and to reach the target in 2045.
Scenario 13 (S13)	assumes no constant rate of net installation but an increased one.
Scenario 14 (S14)	assumes that scenario 12 takes until 2060.

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[3] See https://www.umweltbundesamt.de/en/topics/climate-energy/climate-protection-energy-policy-in-germany/a-resource-efficient-greenhouse-gas-neutral-germany/rescue-scenarios-greenee1-greenee2.

Source: own presentation (Consideo).

The other five fact sheets encompass the following key results:

- Fact sheet 2 emphasises that photovoltaics (PV) may seem inexpensive per kilowatt-hour of energy produced but since it implies higher fluctuations in supply (day/night, winter/summer) it requires more use of inefficient P2L/G. P2L/G as is needed for re-electrification, e-fuels for long-haul aviation and ship transportation, or for industrial purposes (e.g., steel production) makes perfect sense to be produced by PV. But the electrolysers would have to remain underutilised in times with no sunshine – something market forces alone would not support. Therefore, there are voices arguing for using blue hydrogen (based on fossil gas) and synthetic gas and fuels even in areas that could be fully and more efficiently electrified, like heating of buildings or road and rail transportation.
- Fact sheet 3 examines the general availability of resources needed for a global transition towards renewable energy. It underlines the need for high rates of recycling, and it shows the shift from high-grade raw materials to low-grade materials and then recycled materials for repowering. There are economic implications with the shift towards low-grade sources making the transition more expensive and with the shift towards recycling taking away value creation from countries exporting today's raw materials to countries establishing a regional circular economy around the repowering.
- Fact sheet 4 stresses that the global path towards 100% renewable energy requires materials as well as production and construction capacities that could become a constraint. A constant high level of demand with a slight delay in some regions of the world seems to be the most realistic scenario since an acceleration of the efforts towards the year 2050 or so would require massive peaks of resources for only a short time until the same peaks are again needed for repowering of existing installations – a scenario that business models are unlikely to support.
- Fact sheet 5 looks at the potentials from biomass as a substitute for abiotic raw materials, e.g., for steel and concrete and its effect on the overall need for energy. In addition, it shows the potentials of a change of global diet, food waste, and LULUCF to increase the carbon sink of forests.
- Fact sheet 6 examines the potential additional effects from very ambitions resource efficiency efforts according to the WEO's material efficiency scenario (MES).

All fact sheets and scenarios show that the global energy transformation is doable but that it bears the risks that business models would not provide for the needed capacities. That makes it crucial to consider any potential to lower the global demand for energy and for resources as well as calls in question a shifting of the burden towards imports of less efficient P2L/G from other regions, which would require even more installations of renewable energy. While for rich parts of the world it would be possible to import renewable energy and to jump start the global transition with inexpensive high-grade raw materials, other parts of the world could be tempted to continue to use fossil resources once constraints make the transition unaffordable. International policies thus need to address the price developments of crucial resources and the fact that P2L/G capacities need to remain underutilised when there is no surplus of solar or wind energy.

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