Transfer towards climate neutrality - from LCA to a business case

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Abstract. Climate Change Mitigation is high on the agenda. It has been a scientific issues the last years, politics and industry have taken the challenge. Lots of funding and grants are available, engineers are looking into their toolboxes finding some old and many new solutions. We are right at the very start of another industrial revolution – the transfer towards climate neutrality. In the early stages of development many data are still lacking, so LCA might assist to some extent, but not as good as assessing mature industrial processes.

On examples of green steel, synthetic fuels and other carbon capture and utilization (CCU) applications we learned that renewable electricity is the key issue to all decarbonisation or defossilisation projects. No future material processes can greenhouse gas (GHG)-efficiently produce without sufficient build-up of renewable energy capacities including transportation capacities of that energy. The fast build-up of wind and solar power is even more important, than any material or energy carrier process development.

In Life Cycle Assessments assisting the transfer, we should not account for green electricity certificates, if they are bought. Only if new capacities were built up for new electricity demands, decarbonization can be achieved.

1. Introduction

Nations are well at the start to reduce greenhouse gas emissions at a much higher rate than in the last decade. Worldwide, the political targets are set out to reduce emissions to the utmost minimum. Engineers in industry and education have taken up the task and are going into research and realization. Even financial funds are granted in a generous manner. Research and development are much faster than the ecological prerequisites of the new technologies have been accomplished.

Life Cycle Assessment (LCA) and Life Cycle Thinking (LCT) are major tools to assess the new processes and to address the conditions to be successful regarding the GHG targets and other environmental impacts. Scenarios are well underway, even if uncertainty is still high. However, that is typical for any LC assessment of an early stage of development.

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As a result from many LCA studies by the German Environment Agency and the HTW University of Applied Sciences, School of Engineering – Technology and Life in the last years some important conclusions are already drawn and we know by now, which tools from the large LCA toolbox fit in best for the purpose to assess climate neutrality issues.

2. Risk Assessment

The risks from Global Warming are numerous and will effect everybody. Figure 1 gives a plot of relative and absolute changes expected for Germany.

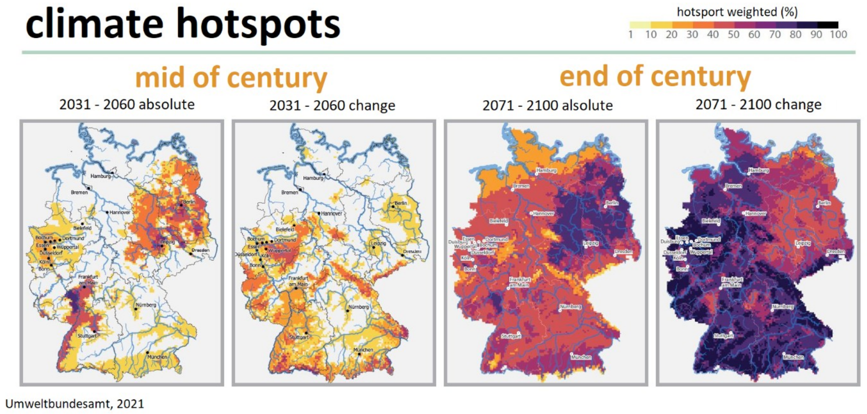

Fig. 1. Relative and absolute climate hotspots in Germany. German Environment Agency, 2021.

The reaction by most countries on such scenarios is to target for GHG neutrality in the near future. Figure 2 demonstrates the pathways laid out for Germany until 2045.

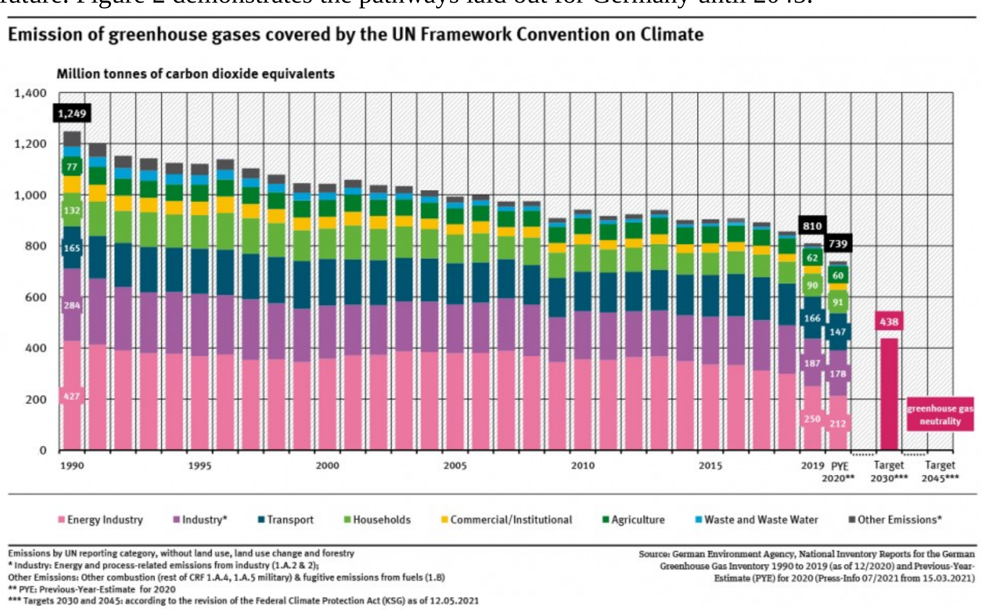

Fig. 2. GHG emissions from Germany 1990 to 2019, estimated for 2020 and targets 2030 and 2045 German Environment Agency, 2021.

3. Decarbonisation and Defossilisation

There are two major paths towards greenhouse gas neutrality:
Decarbonisation: No use of carbon in all industries, where possible, especially energy conversion.
Defossilisation: Switch from fossil feedstock to non-fossil or cycled materials.

Some major findings in view of a national responsible authority:

Calculated over all relevant sectors like industrial production, traffic and households, more than 90 % of the nation's GHG emissions are directly or indirectly stemming from fossil energy conversion. That number sums up electrical power plants as well as combustion cars and home heating, among others. Despite the energy efficiency potentials of all these processes a large share of that energy conversion needs to be substituted by renewable energy resources. This kind of transition (**decarbonisation**) is based on well known technologies and also well known technical and economic risks. There are multiple ways of exchanging the energy sources. The electrical networks need to be reconstructed to the new distribution between energy sources, storage and demand. Several processes need to be electrified (i.e. cars, home heating, chemical processes like cracker). In all scenarios of the Rescue study [1] the demand for electrical energy is rising. From today's 513 TWh (2018; [2]) to something between 850 TWh and 2,700 TWh.

Since this increase in demand, the renewable energy target is to be set not at 100% but something at least around 150 to 200% of today's consumption. The overall primary energy use (CED) will nonetheless decrease because the thermal energy transition by low efficient Carnot processes will nearly completely stop.

We urgently have to look at the additionality of any new demand created by the transitional processes. Any new energy demand must be covered by newly built renewable capacities. This should already be incorporated in the funding rules.

The **defossilisation** pathway shifts the feedstock for industrial processes from fossil carbon to non-fossil or cycled materials. These could stem from waste like plastic waste. Either by direct mechanical recycling or indirectly by chemical recycling new plastic might be produced from these resources. In a discussion paper [3], the German Environment Agency showed that all carbon cycling potentials will most likely not be sufficient to meet the carbon demand in Germany (today about 20 mil. t of carbon as C). So a major source of carbon will be the atmosphere. Taking CO_2 directly (DAC – direct air capture) or via biogenic processes (i.e. plants, bioreactors, sustainable biowastes) will serve as the major source of carbon feedstocks.

Most scenarios like green steel (figure 3), synthetic fuels or chemicals by the use of CO_2 show less contributions to GWP in comparison to fossil equivalents only, if more than about 80% of renewable sources are feeding the electricity grids. More information on this is provided in table 1. Depending on the country we are looking at, this 80% margin (~120 g CO_2/kWh) will not be accomplished within the next decade.

Every industrial country heavily needs carbon for various applications, especially chemicals. CO_2 might be a decent resource of carbon; however, from first results [3] it seems to be the least effective source. Since CO_2 is low on inner energy, most chemical applications need a lot of (renewable) energy to produce something useful from CO_2. All kinds of carbon cycling at a lower oxidation level is more useful than using CO_2.

If fossil CO_2 is used in such cycles once or more often, the emission is only shifted by time and location. For all products using CO_2 as feedstock that is only useful, if the indirect GHG emissions from the energy needed are lower than the emissions of the fossil counterparts.

Conclusion: All strategies to fuel the expansion of renewable energy capacities must get priority over the circulation of carbon. We need to develop the carbon circular economy processes now, to have them handy, when sufficient renewable energy is available. **Decarbonization is more important than defossilisation.**

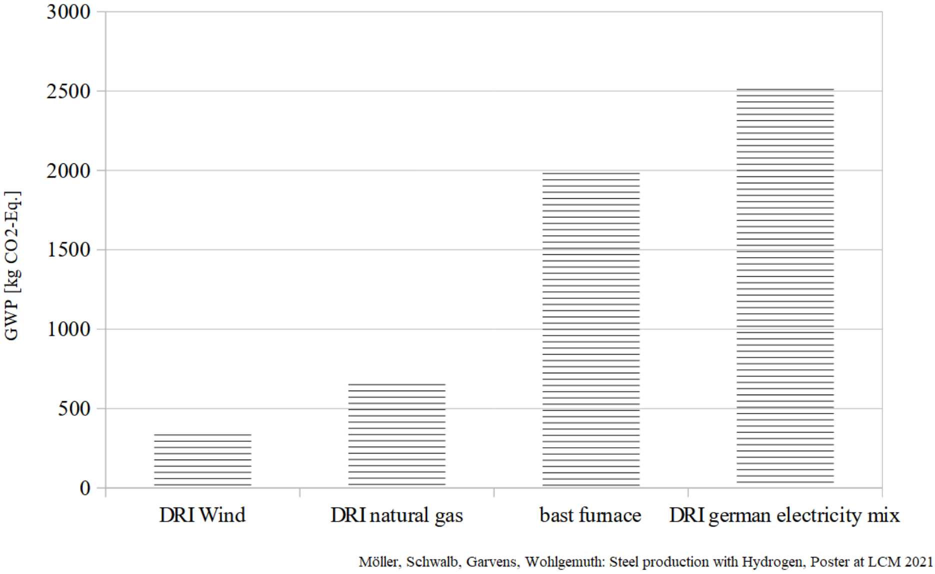

Fig. 3. New direct reduction process (DRI) with hydrogen was developed and will be upscaled in the next years. In the shown case study [4], wind energy GWP is better than the reference blast furnace, on today's electricity mix the DRI is much worse.

Table 1. Substitution effect by 1 kWh of renewable energy used in various PtX processes. [3]

Use of regenerative power			Substitution of fossil supply				
regenerative supply			fossil reduction			Substitution ratio	avoided greenhouse gas emissions in gCO_{2eq}
Input	Technology	Supplied end-/use energy		Technology	Input		
1 kWh regen. power	PtH Heat pump	3,3 kWh (thermal)	3,3 kWh (thermal)	Condensing boiler (105%)	3,14 kWh natural gas	3,14	~ 640
1 kWh regen. power	e-car (80%)	4,6 km	4,6 km	combustion engine (28%)	2,6 kWh liquid fuel	2,8	~ 690
1 kWh regen. power	PtH Direct electric	0,95 kWh (thermal)	0,95 kWh (thermal)	Condensing boiler (105%)	0,91 kWh natural gas	0,91	~ 185
1 kWh regen. power	PtG – H2 material	0,74 kWh (hydrogen)	0,74 kWh (hydrogen)	Steam reforming (85,2%)	0,87 kWh natural gas	0,87	~ 180
1 kWh regen. power	PtG – CH4	0,58 kWh (methane)	0,58 kWh (methane)		0,58 kWh natural gas	0,58	~ 120
1 kWh regen. power	PtL	0,5 kWh (liquid fuel)	0,5 kWh (liquid fuel)		0,5 kWh liquid fuel	0,5	~ 135

4. LCA of transfer

4.1. Prospective LCA

pLCA is done by adaptation of process data, impact assessment, evaluation and interpretation for the future scenario. In decarbonisation and defossilisation scenarios nearly every scenario is prospective. All data have added uncertainties ending in much broader result ranges. Significant results in scenario comparisons are more unlikely the further into future a model is built for.

Most of the learnings for climate neutrality scenarios are also possible by LCAs based on today's data. Energy, especially renewable energy plays an important role. Therefore it is not feasible to regard renewable energy certificates only. Most of them do not promote the build up of new capacities, which are urgently needed. Each project today and possibly also in the next decade need to build necessary renewable energy capacities for the processes by themselves.

4.2. System Boundaries

In cradle-to-gate we assume the same fate for functionally equal materials after their production. Basically, that is true despite a different impact of circulated carbon (taken from atmosphere) and fossil carbon or circulated carbon from fossil sources in end-of-life.

The circulation of carbon does not mean, that the final emission is GWP-neutral. It still has to be regarded, if a circulated carbon originates from previously fixed sources (earth). Biogenic carbon can completely be accounted for as carbon from atmosphere in this sense. In LCI it is always useful to account for the (biogenic) uptake and emission in a model, especially, if circulated carbon from various sources is included in the model.

By that accounting and cradle-to-grave boundaries, no unfair comparisons are to be expected. However, regarding allocation of multi output processes another clear recommendation shall be given, here.

4.3. System Expansion

Although infrequently used, system expansion (on cradle-to-grave) gives a true picture, if a complete system is really leading to GHG neutrality, even negativity or still adds to the GHG content of the atmosphere.

If any other kind of process allocation is used, information from the interpretation is limited to "better (equal, worse) than reference". These kinds of answers were sufficient in the last few decades; however, they are not any more. Since the target is set out to neutrality (net zero emissions), we need LCA results which reference the net zero threshold.

4.4. Time Effects

The number of carbon cycling loops has got no effect on the final impact towards GWP if fossil CO_2 was initially used. All cycling leads "only" to a time-shift and dislocation of the emissions.

Like in a landfill, where a degradable material will lead to methane emissions in some time in the future, the carbon cycling will also finally lead to emissions, if the pathway is not re-directed to storage.

Regardless, if the emission takes place in 20, 50 or 120 years in future, the emissions must be fully accounted for at the process, which initially uses the material and is responsible for sourcing of the material. All subsequent processes – i.e. if they are using the waste from the initial process – do not need to account for the feedstock emissions. Their "burden" is to produce something useful from that waste. Waste might be residual solid or liquid waste as well as gaseous CO or CO_2.

4.5. Burden shifting - LCA is not just about GWP

LCA is a powerful instrument not just on GWP impact accounting. Although climate change is a major task and on issue everywhere, we need to think outside the box.

If societies are setting GWP targets i.e. for 2050, it has to be closely observed, how other environmental compartments react [5]. Only a set of six to ten or even more environmental indicators in LCA projects serve the need for a sufficient holistic view.

Large changes in fuels and feedstock sourcing as well a major changes in industrial production will have a societal impact, too. It is useful always to model social effects in LCI based on the newly developed guidelines, even if the data are not sufficient by now. Each addition to social data serves our all need for a full picture on this in future.

4.6. Actual Process data in LCA databases

Several databases serve unit processes, where it is possible to attach today's energy models or future scenarios. However, lots of processes come at least partly aggregated for some reason or another. For future process projections, all energy related processes must be fully detachable.

Case studies show how sensitive LCA models are, if even small amounts of by-materials cannot be modelled partly or fully decarbonized. On the other hand, this shows how sensitive the climate indicator is and how large the task is to implement full decarbonization in future industry processes.

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