Swiss National Science Foundation

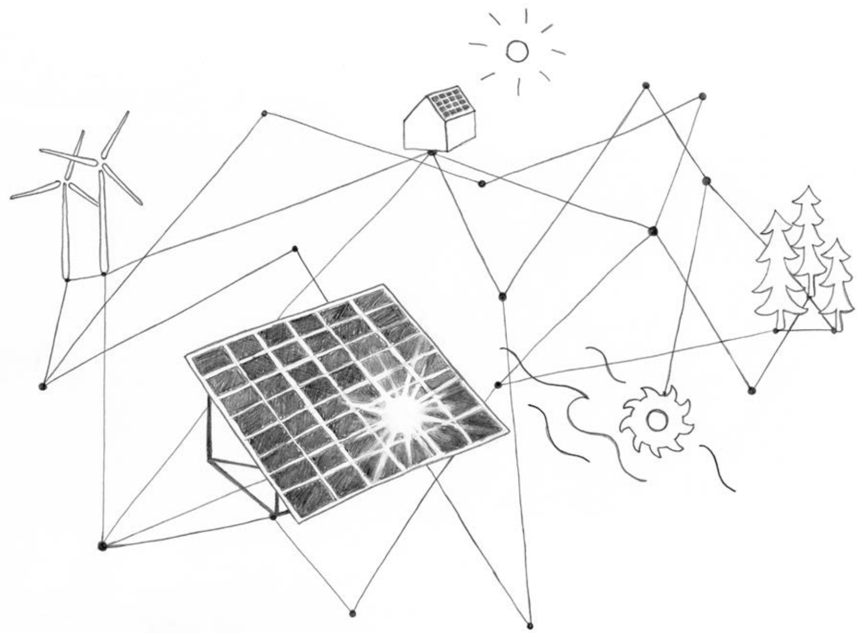
Sustainable Economy
National Research Programme

Laboratory for
Applied Circular Economy
(LACE)

Synthesis note of the LACE project n°2

Powering a circular economy with renewable energies?

Solar energy is the renewable resource presenting the greatest global potential to satisfy the future energy demand powering a growing population and the development of a circular and sustainable economy.



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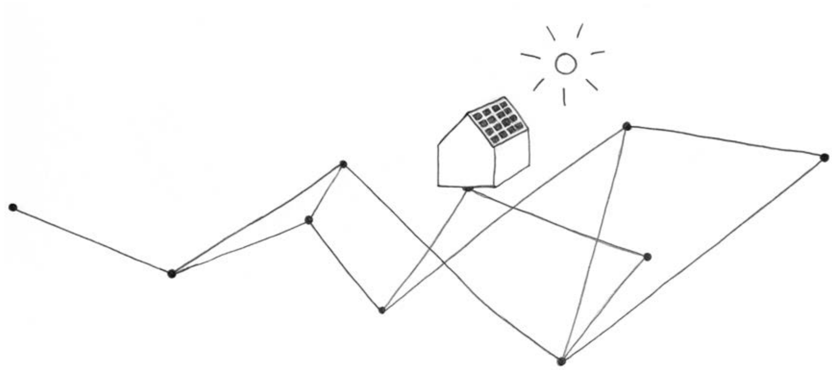


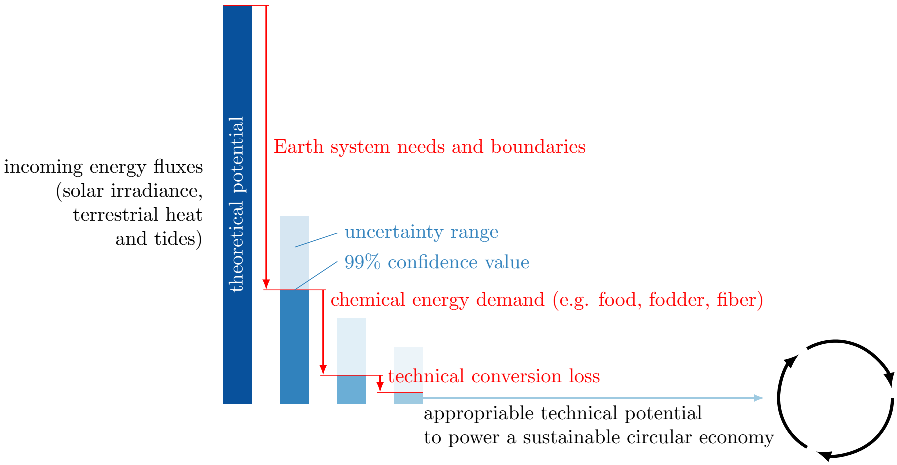
Powering a Circular and Sustainable Economy

Circular economy is perceived as promising strategy to decouple economic growth from natural resource use and environmental degradation. Yet, the discourse on circular economy has focused so far on materials and solutions such as recycling, reusing, repairing, without worrying about the availability of the necessary energy to implement these activities. Because of the huge impacts on the environment and human health deriving from the use of fossil fuels, as well as the depletion of uranium stocks and risk of catastrophic accidents from nuclear energy, one cannot consider any economy based on them as sustainable. Thus, in the context of an aggravating climate crisis and biodiversity loss, **a transition towards renewable energy is crucial to power a circular economy in a sustainable manner.**

Renewable energy fluxes entering the planet power the Earth system, e.g. the water cycle. Human demand for energy, food production or bio-based materials may interfere and compete with the Earth system's energy needs. This "competition" raises the following question: **Can humanity satisfy its technical energy demand with renewable energy resources without transgressing Earth system boundaries?**

The above question is at the core of the research carried out by researchers of Empa, the Swiss Federal Laboratories for Materials Science and Technology, in the context of the Swiss National Research Programme "Sustainable Economy" (NRP 73) – project "Laboratory for Applied Circular Economy" (LACE). This research published recently develops **a broad theoretical analysis framework to estimate the renewable energy fluxes that are potentially available at a global scale to power a circular and sustainable economy**. This is done by considering and respecting relevant Earth system boundaries and the human demand for chemical energy, as well as taking into account conversion losses of current technologies.

How much renewable energy can be used?



Renewable energy fluxes entering the Earth system and being appropriated to satisfy natural and human needs (from the authors).

The authors start from the total amount of renewable energy fluxes entering the Earth system and name it "theoretical potential" (see figure above). This amount includes solar irradiance, terrestrial heat, and tides. The fraction of this theoretical renewable energy potential that is available to power the technosphere, e.g. a circular economy, is named "appropriable technical potential" and is limited by three factors:

1 ***Earth system needs:*** most of the entering renewable energy is essential to drive natural processes. For example, the water cycle cannot function without the sun providing the energy for the evaporation of water and for the transport of clouds by winds. The planetary boundaries framework (see box on page 4) is used to describe the limits above which human appropriation of renewable energy would cause irreversible changes to the Earth system. In the study, two boundaries are explicitly considered: land use change (because harvesting renewable energy mostly depends on the available land surface) and freshwater withdrawal (which is important for hydropower for example).

2 ***Human need for chemical energy:*** a large share of the remaining renewable energy is used by humans for food production and to satisfy other uses of biomass, e.g. fibers for clothing. Hence, this energy is not available for technical energy use. As human activities already surpass several land use related boundaries, further appropriation of chemical energy, for example for the production of biofuels, isn't considered sustainable.

3 ***Technical potential:*** deducting the renewable energy needed for the Earth system as well as the human chemical energy demand of the current and future human population from the theoretical potential, results in the renewable energy available to power the technosphere. Considering losses to convert this to electric energy, the appropriable technical potential can finally be estimated.

What are planetary boundaries?

The *planetary boundaries framework* defines a safe operating space for societal development in the long run, based on the Earth's biophysical boundaries. In this framework, the limit values of nine different key Earth system processes are specified. In this study, the following boundaries are considered.

Land use change is one of the key drivers in altering Earth system processes. It describes how much of the native vegetation of an area has been removed, setting a sustainable maximum level for the removal of vegetation. This is important since human disturbances of natural ecosystems can have direct effects on the climate system and biodiversity. The planetary boundary focuses on forest removal (because of the strong impacts of deforestation). However, in this study, non-forest biomes (such as grasslands, tundra, etc.) are also considered in order to broaden the analysis.

Freshwater use describes the limit for the sustainable use of river runoff by humans. It specifies the maximum monthly river withdrawal, based on the average between the lowest and the highest values of annual rivers' flow.

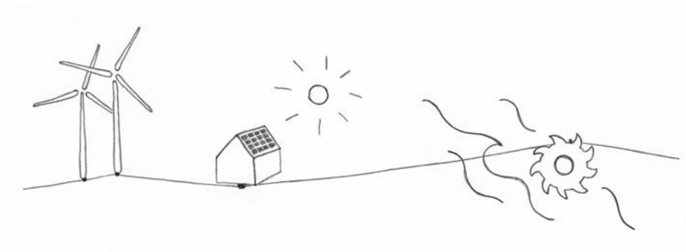
Which renewable energy is key for a sustainable circular economy?

Of the renewable energy fluxes entering the Earth system, solar power vastly dominates (99.97%) – making it the pivotal power source for the functioning of all natural and anthropogenic processes. Subtracting the power demand for Earth's processes and human chemical energy demand leaves only 0.04% of the theoretical potential to be converted to technical energy without violating land use or freshwater use boundaries. Although this fraction appears small, it is in fact about one order of magnitude larger than the total current technical energy demand. **The appropriable technical potential is dominated by direct solar energy conversion (98%).** All other renewable energies sources (e.g. wind- and hydropower or terrestrial heat) offer appropriable technical potentials which are some orders of magnitude smaller. Thus, from a global perspective, all other renewable energy resources are secondary – which is not to say that they are not important locally, in particular to complement the intermittency of solar power.

The calculated appropriable solar power potential can largely cover the current technical energy demand, also leaving room for a substantial increase in human energy demand. This is important in view of a potentially increased energy demand to satisfy the needs of a growing population, to balance the uneven distribution of renewable energy, to mitigate the environmental impacts of the past and future human activities and to support the development of a circular economy.

The calculations also show that if worldwide energy demand reached the guidance value of a 2000-watt society, solar power from the built environment alone could be sufficient. Increasing the energy demand per capita worldwide to today's average in Switzerland would, however, require an additional solar energy harvest on up to 10% of all desert surfaces.

Solar power not only offers the most significant potential to satisfy human energy demand, it is also currently the most underdeveloped. Particularly interesting is its potential to be expanded on sealed surface of existing buildings, not needing any further land appropriation and thus without additionally challenging the planetary boundaries. The situation is the opposite for hydropower or biomass, which are already heavily exploited and close or beyond their ecological safe limits.



Conclusion

The study introduces an approach to derive limits to appropriable renewable energy, which could be made available to power a sustainable circular economy. The authors conclude that direct solar power conversion is key and necessary to ensure that the demand of the growing future population is met and to enable a circular economy with renewable energy. The results demonstrate that solar power harvested with current technologies on today's built environment could supply a global 2000-watt society. All other renewable energy resources could then complement solar power and help to mitigate its intermittency. Deserts can be seen as a reserve for further development of solar power after all other potentials have been implemented. However, energy still needs to be used wisely and efficiently, considering the complexity of transitioning away from fossil fuels and nuclear power.

To provide more detailed solutions, different geographic scales could be considered, adjusting the sustainable energy mix for the local conditions. Ideally, the proposed approach could be extended to evaluate scenarios for nations and regions. The time resolution is currently one year thus daily and seasonal variation of renewable energy fluxes are not considered. On the demand side, products could be designed to accommodate and compensate for such fluctuations. Buildings are a good example, having a large energy demand and at the same time presenting a high potential for energy provision.

Method

To compare and quantify the different energy sources and renewable energy technologies, electric energy is used as the basis for comparison. Using electricity as a common "currency" is justified because most renewable energy technologies can convert Earth system energy into electricity and because the electrification of energy is considered key for a post-fossil society.

To ease the calculations, the approach uses a simplified model of the system: no transitions nor temperature changes are considered, stocks are considered constant (no changes in land or forest biomass), and spatial or temporal variations are also neglected. Moreover, neither the resource needs nor the impacts due to the lifecycle of the technologies are considered in the model (production, installation, decommissioning, etc.).

Because of the complexity stemming from developing precise models at the global scale, a precautionary approach is applied. This means requiring a chosen low probability ("worst-case") of violating Earth system boundaries or technical limits by setting a 99% confidence level (meaning that there is a 1% chance that the estimated appropriable technical potential is ecologically or technically not viable, while 99% of plausible potentials are above the boundary set for each resource). Because of the uncertainty linked to the development of future technologies, the precautionary principle is also applied for the technological parameters, being based on state-of-the-art technologies.

In the calculations of the appropriable land, three different scenarios, based on different types of land use (cropland, pasture, built environment), are implemented:
- *Scenario 1*: *proportional* – appropriable land divided according to the relative share in the year 2000;
- *Scenario 2*: *reduce pasture* – the area of built environment and cropland is kept at the level of 2010 and pasture is rescaled to fit the planetary boundary; and
- *Scenario 3*: *maximize cropland* – based on scenario 2, cropland is maximized whenever possible at the cost of pasture to increase possible food supply for a growing population.

These land use scenarios define the area available for technical energy conversion. They are developed in order to test the influence of different land uses on the final results. Since the chosen land use scenarios have proven to have little influence on the results except for solar in the desert, the scenario 3 is used in the paper.

For freshwater withdrawal, the maximum monthly river withdrawal is used, approximating the boundary with the lowest and highest values.

Three different indicators are used to evaluate energy mixes against their appropriable technical potential at different levels (from products to the global economy). The indicator $\tilde{\tau}_i$ describes the pressure on an energy resource, by comparing the power used from each resource to its appropriable technical potential.

Another useful indicator is the *renewable energy fraction*, which calculates how much of the total energy demand is provided from renewable energy resources.

Finally, the *renewable energy indicator* is introduced to compare the actual energy mix with the theoretical appropriable technical potential. This is important since an optimal use of all renewable energy resources is achieved when the actual energy mix is the same as the potential energy mix.

About the NRP 73

This research project is part of the National Research Programme "Sustainable Economy: resource-friendly, future-oriented, innovative" (NRP 73) of the Swiss National Science Foundation (SNSF).

NRP 73 aims to generate scientific knowledge about a sustainable economy that uses natural resources sparingly, creates welfare and increases the competitiveness of the Swiss economy. NRP 73 takes account of the environment, the economy and society as well as all natural resources and stages of the value chain.

73 NRP **Sustainable Economy**
National Research Programme

Further information on the National Research programme can be found at:
www.nfp73.ch

About the LACE

The Laboratory for Applied Circular Economy (LACE) is an inter- and trans-disciplinary project that gathers researchers from three Swiss higher-education institutions, and from various disciplines: environmental and material sciences, business administration, as well as law and political sciences. The LACE project is working together with seven well-known partner companies in order to show how the resource-efficient patterns of the circular economy and related business models can be introduced into the value chains of the participating companies. The aim of this project is to demonstrate that the principles of circular economy can be ecologically beneficial and profitable for Swiss companies. The sanu durabilitas foundation is knowledge-transfer partner of the LACE project.

Empa Materials Science and Technology

Universität St.Gallen

Unil UNIL | Université de Lausanne

Further information on the Laboratory for Applied Circular Economy can be found at:
www.nrp73.ch/en/projects/circular-economy/laboratory-for-circular-economy

About sanu durabilitas

The sanu durabilitas foundation is an independent Think and Do Tank based in Biel/Bienne. Its aim is to develop new practice-oriented and effective solutions for the transition towards a sustainable Switzerland which are being applied in economy, policy and public administration, and also to improve the institutional framework conditions for sustainability. In collaboration with partners from research, business, politics, administration and civil society, sanu durabilitas identifies promising solutions, develops them further, tests their application in the field, draws up recommendations, and brings them to the attention of decision-makers and the general public. The current focus areas of sanu durabilitas are circular economy, sustainable use of soils, and social cohesion in a changing society.

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Further information on sanu durabilitas can be found at:
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