Rödl & Partner

Series on the energy transition

THE PRIMARY ENERGY FALLACY

While Germany already covers more than half of its electricity demand with renewable sources[1], the share of renewables in primary energy consumption is relatively small: just under 20 percent[2]. At first glance, a complete switch to renewable energy seems like an unattainable goal. This argument is often used when discussing the potential of the energy transition: that the transition of the electricity sector is feasible, but that a transition of the primary energy supply cannot be achieved with renewables. This is a widespread fallacy.

As Jan Rosenow describes in his paper “Have we been duped by primary energy fallacy?”[3], when considering primary energy, the crucial mistake is to overlook fundamental differences in the efficiency and utility of energy sources and technologies. To put it simply: it is not necessary to replace all primary energy with renewables if new technologies can provide the same energy services more efficiently.

The fallacy of fossil fuel dependency

Primary energy consumption consists of the energy content of unrefined energy sources such as coal or crude oil, which can be used directly but are usually first converted into marketable secondary energy sources like gasoline or electricity. Primary energy consumption is calculated as the sum of all such energy carriers produced domestically plus the balance of imported and exported quantities and changes in stock levels minus supplies bunkered on the high seas[2]. The misconception that leads many people to believe that the demand of fossil fuels is insurmountable results from the failure to distinguish between inputs (coal, oil) and outputs (heat, transport). Equating primary energy inputs with energy services or outputs grossly overrepresents[3] conventional energy sources.

The following Sankey diagram of the German energy system shows the complex path of various energy sources to the final service.

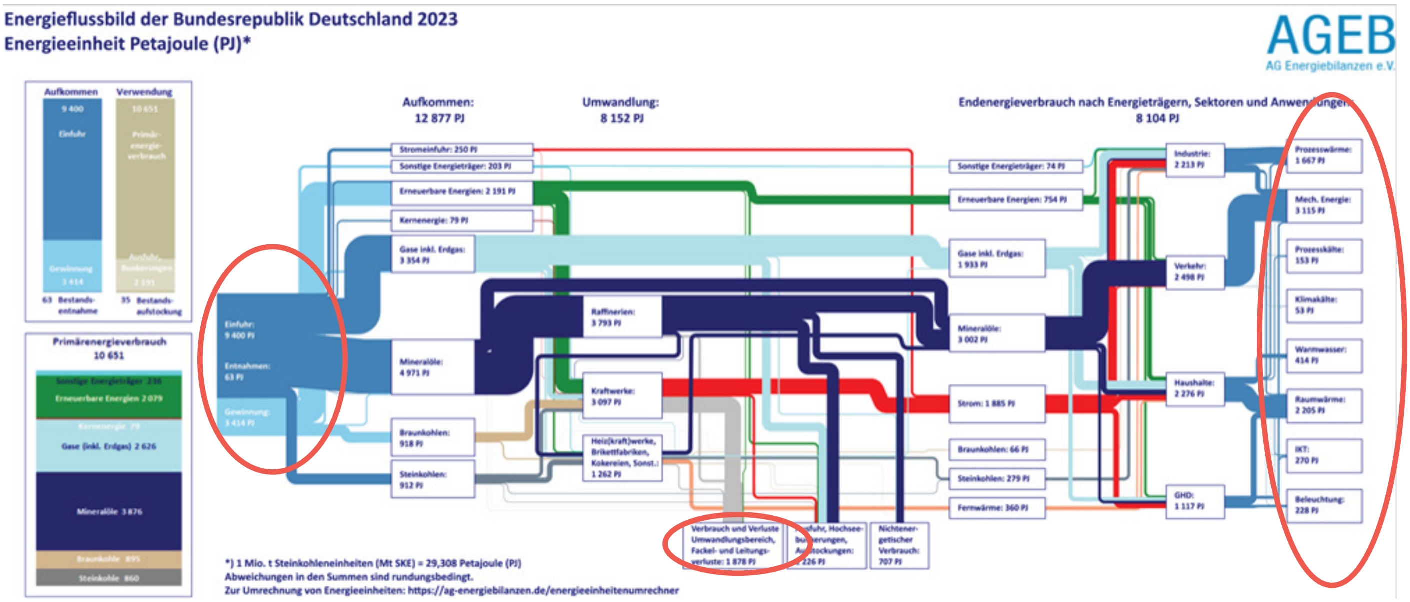

Figure 1: Energy flow diagram of the Federal Republic of Germany in 2023, source: AG Energiebilanzen

The diagram clearly shows that Germany not only imports the majority of its primary energy inputs (circled on the left), but that almost 20 percent of energy is lost during conversion processes (circled in the middle) before providing useful energy services to final customers (circled on the right). The reason for these losses lies primarily in technology. While renewable technologies like wind and solar produce marketable electricity directly, fossil fuels must first be converted or refined. On average, the efficiency of fossil fuel power plants in Germany is only 45 percent[5]. In fact, authorities such as the IEA and EIA used to apply a so-called partial substitution method[6] and multiply the share of renewable electricity sources such as hydropower by a fossil fuel equivalency factor of about 3 to make their theoretical primary energy effect comparable to fossil energy sources. This inefficiency is not only harmful to the environment, but also expensive — in 2024 alone, Germany imported gas worth 19 billion euros and oil worth 45 billion euros[7]. The loss during energy conversion costs the German economy over 10 billion euros annually. While conversion losses can be mitigated by utilizing combined heat and power production, in the current fossil fuel system, we are still wasting 10 billion euros a year through chimneys and cooling towers, or burdening rivers with waste heat.

In addition to the environmental damage and costs, this inefficiency also distorts the picture of the German energy system. Of the 10,600 PJ (petajoules) of primary energy consumed, only about 8,100 PJ are ultimately used[4]. Renewable energies are therefore underrepresented in primary energy analysis. Since they have virtually no conversion losses and require no energy for fuel shipping and transportation[8], renewable power sources like solar and wind can offset three times the amount of fossil fuels.

Efficiency gains through electrification

From this perspective, it is obvious that if superior alternatives exist, it makes no sense to stick with extremely inefficient technologies. An increase in efficiency would reduce overall energy consumption, make it much easier to achieve climate targets, and not require any compromises in terms of the ultimate benefit (the energy service) for consumers (or businesses).

A clear illustration of the efficiency advantages of new technologies is the heat pump. While conventional heating systems such as gas or oil boilers generate approximately one unit of heat for each unit of energy input, modern heat pumps typically deliver four units[9] of heat from one unit of electricity. This four-fold efficiency means that the same heating output can be achieved with significantly less primary energy input than even with the most efficient condensing boilers.

Another area where the efficiency benefits of electrification are evident is electric mobility. Electric motors convert around 80% of the energy supplied into motion. Considering additional losses, for example when charging the battery, electric cars achieve an overall efficiency of around 65 percent. In comparison, the efficiency of diesel engines is around 45 percent and that of gasoline engines under optimal conditions is 30–35 percent[10]. Even the Sankey diagram in Figure 1 omits this fact. If energy losses during fuel supply are also taken into account, i.e., the steps from the well to the vehicle tank, only around 20 percent of the energy originally used is actually utilized[11]. As can be seen in Figure 1, a large proportion of the energy used in transport is still obtained from fossil fuels, and a switch to e-mobility in this sector, which accounts for around 2,500 PJ, would drastically reduce sectoral energy demand. Incidentally, a switch to hydrogen or so-called e-fuels is not a realistic alternative. A study by Wien Energie shows that hydrogen vehicles exhibit efficiency levels of 22 percent and e-fuels even less, merely 13 percent, far from the efficiency of modern electric vehicles[12]. Hydrogen and e-fuel technologies have the opposite problem to conventional energy sources – they do not need to convert energy carriers such as oil or gas into electricity. Instead, they convert high-value electricity into lower-value but easily transportable liquid energy carriers in energy-intensive conversion processes.

While electric cars and heat pumps – although not exclusively – mainly bring efficiency to the private consumers, it is heavy industry that is still largely dependent on conventional and therefore inefficient energy in Germany[4]. Electric boilers play a key role in decarbonizing process heat. Many industrial applications, such as in the chemical, food, or paper industries, require large amounts of heat at high temperatures – previously mostly covered by natural gas or other fossil fuels. Electrode boilers or piston compressor systems can provide this process heat efficiently and emission-free, provided they are powered by electricity from renewable sources. Electric boilers achieve almost 100 percent efficiency in converting electricity into heat and, thanks to their short response time, offer great flexibility for industrial processes with changing load requirements. Much higher efficiencies can be achieved with heat pumps. Unlike traditional boiler systems, there is no need for fuel storage, emission control measures or long ramp-up times. In addition, electric boilers can be used specifically to address grid bottlenecks by converting surplus electricity into heat and using it on site or storing it temporarily in thermal storage tanks. The sector coupling of the power and heat systems can accelerate the transformation of German industry, but has not been sufficiently addressed in the conventional primary energy balance to date[13]. And even without electricity, environmental heat, especially geothermal energy, can be used very efficiently to produce heat through direct use or through combination (i.e., with a heat pump). Drilling naturally requires a high initial investment but is also generously supported by the BEW program[14].

Electrification in figures

Looking at Figure 1, it can be seen that in Germany more than half of final energy consumption occurs in households and transport. Space heating and mechanical energy (mobility) in particular stand out as the largest items here.

The scientific paper by Oxford professor Nick Eyre shows that a complete conversion of the global energy system could cut demand by **40 percent** and thus reduce global annual consumption from **416 EJ (exajoules) to 247 EJ.**

The transport and buildings sectors account for most of the current demand for mechanical energy and space heating and together represent more than half of the reduction in this projection. Heat pumps (possibly with geothermal energy) and e-mobility would be drivers of change due to their greater efficiency. In industry, the percentage of electricity used would double, in the building sector it would almost triple, and in the transport sector it would be about 30 times greater than current level 14[15]. Through progressive electrification, we can reduce dependence on fossil energy sources and make the overall energy system significantly more efficient and, through decentralized generation, also more secure.

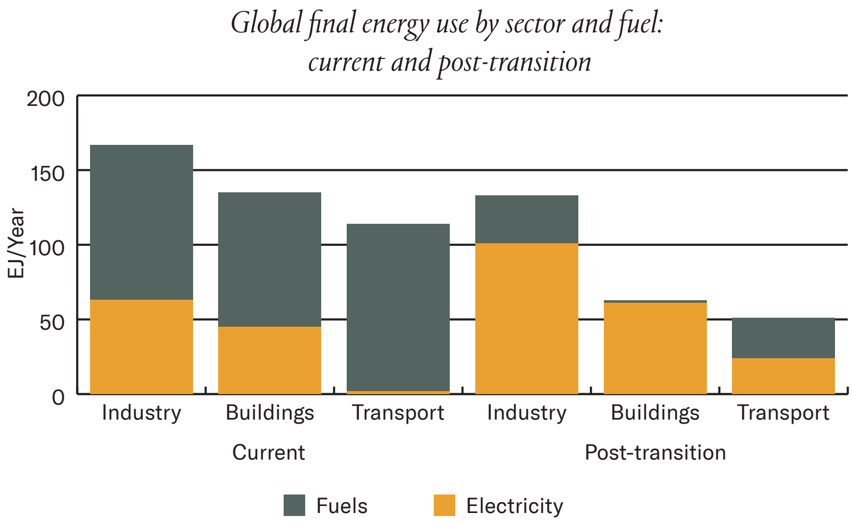

Figure 2: Global final energy consumption by sector – current and post-transformation

Conclusion

The widespread misconception that a switch to renewable energies is not possible because their share of primary energy is low fails to recognize the fundamental inefficiency of conventional technologies. The misguided focus on primary energy conveys a distorted picture of actual energy flows, as it ignores conversion losses and efficiency gains through new technologies. With the increasing use of heat pumps, geothermal energy, e-mobility, and electrified industrial processes such as electrode boilers, total energy consumption will be significantly reduced – without any loss of comfort or performance. The primary energy indicator will inevitably fall, not because less energy is being "provided," but because the same services can be provided with less input. The supposedly low share of renewables in primary energy should therefore not be used as an argument against the energy transition – instead, it shows how outdated and misleading conventional energy accounting is. A successful transformation of the energy system does not mean replacing 100 percent of today's primary energy but using a fraction of it much more intelligently through electrification and efficiency. Let's get to work!

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