Chapter 2
Global Energy Situation

2.1 Primary Energy Resources

The main global primary energy resources consist of the traditionally used fossil fuels, such as coal, oil, and natural gas, which in the last century have substantially replaced wood, and which have notably been supplemented by nuclear 'fuels' (^{238}U) within the last couple of decades, due to a considerable increase in global primary energy needs.

Solar energy is the driving force for almost all types of 'renewable energy'. The input to the outer atmosphere of our globe amounts to 175,000 TW (see Fig. 2.1) and exceeds the present global primary energy requirement per unit time of about 15 TW by four orders of magnitude.

With an assumed technically usable fraction of only 1 % and a hypothetical overall conversion efficiency of solar light of $\eta = 10^{-2}$, solar radiation would theoretically be sufficient to provide for the primary energy needs of the world, even with further population growth. However, the use of that amount of solar light would have enormous impacts on the global average temperature and thus on the global climate. Despite the fact that solar radiation is available in such huge amounts, for environmental reasons mankind may well be unable to exploit it in the way that primary energies have been used so far.

Amongst all types of light reaching the Earth's surface, such as from stars, from the Moon, solar radiation is by far predominant and is entering almost exclusively into the entire global energy flow balance. Behind solar radiation with $P_{\text{rad, surf}} = 89{,}000$ TW, the theoretical potential of wind energy ($P_{\text{kinet. air}} = 400$ TW) and of biomass ($P_{\text{biosphere}} = 100$ TW), each of them also driven by solar radiation are the next candidates for renewable energy utilization; in comparison with these, the theoretical potential of hydraulic power is relatively small ($P_{\text{hydro}} = 5$ TW) ([1–3]

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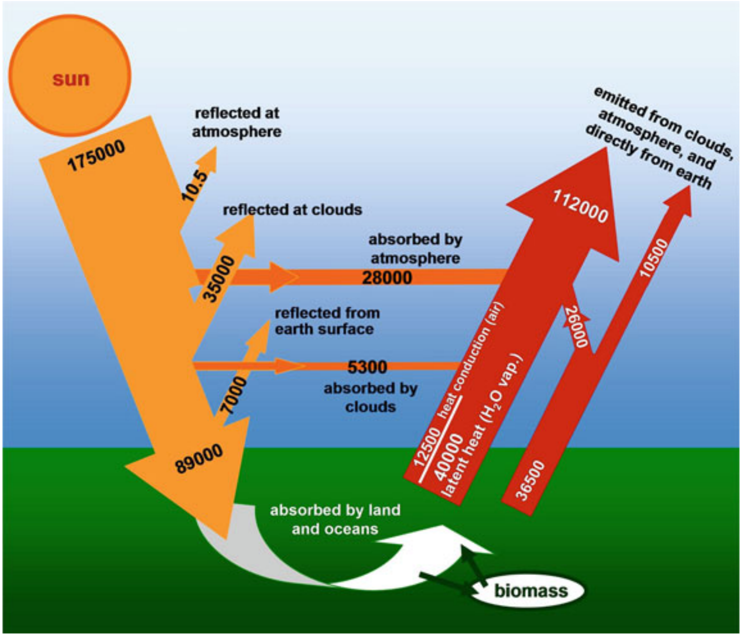

Fig. 2.1 Global energy flow budget. Numbers in TW. Data from [1]

and see Fig. 2.2 for details).[1] Of course, for each of these theoretical potentials, the so-called technically usable part amounts to a substantially smaller fraction only.

2.2 Primary Energy Demand

The present global primary energy demand per time amounts to about 15 TW. Divided amongst 7×10^9 human beings, this implies an average value of 2.2 kW/capita. The distribution of the primary power demand and use diverges widely between 'rich' consumers in industrialized countries (up to 12 kW/capita) and extremely 'poor' consumers elsewhere (< 0.1 kW/capita). The average as well as the individual numbers may be compared with the 'biological' value of (0.06–0.07) W/capita for adult humans not engaging in any specific physical activity, i.e., only sleeping or sitting.

In view of an increase in regional industrial activities and due to the moral requirement to provide a better energy supply to the large number of poor people,

[1] The exploitation of locally available types of renewable energies, such as tidal, geothermal, ocean waves, etc., should certainly be considered. In the global balance, however, their contribution is only marginal.

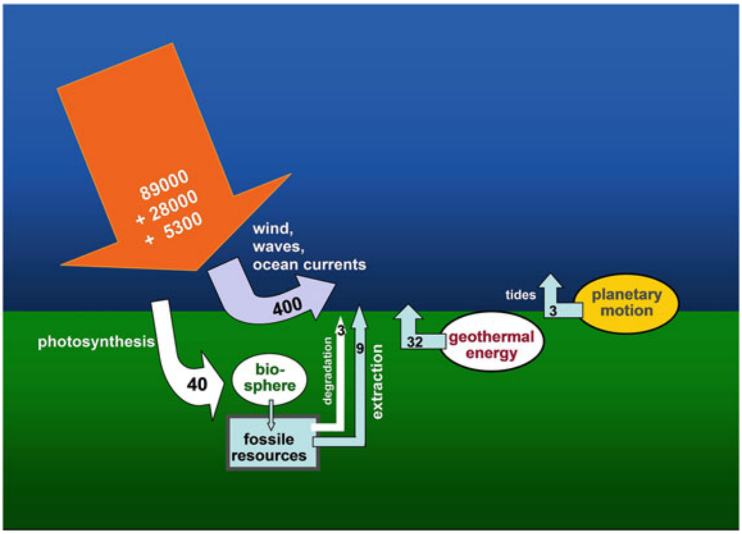

Fig. 2.2 Global budget of renewable energy flows driven by solar insolation of the atmosphere and the Earth's surface. Data from [2]

one must expect an even greater increase in global primary energy demand than would be implied by the corresponding rise in population. In the future, a straight replacement of traditionally used fossil energy carriers by renewable energies, and in particular solar energy, will definitely not suffice for a 'business as usual' strategy. Indeed, we will need to change our appreciation of the value of energy and our relationships with it. In this sense, we should regard the contribution of electrical power delivered from solar cells by conversion of sunlight rather as an option than as a panacea.

2.3 Production of Solar Cells and Modules

Regarding the production of solar cells and modules and their use for solar energy conversion, several aspects must be taken into account, including the total energy needed for preparation versus energy output over lifetime, availability and costs of material and components, cost of investments, and return on investments. For a fast-growing business area like solar cells, the availability of sufficient numbers of personnel with the appropriate training in science, technology, and maintenance may also act as a bottleneck for the necessary speedy development of a photovoltaic industry.

To appreciate what industrial production would involve, we may calculate the energy and material needed to replace the electrical power output of a nuclear power plant with nominal 5 GW production. For this purpose, we assume singlecrystalline silicon (c-Si) solar cells with a module efficiency $\eta_{mod} = 0.15$, exposed to an average central European insolation of 100 W/m^2. Replacing 5 GW would then require a total module area of $A_{mod} = 3.3 \times 10^8\,m^2$ ($18 \times 18\,km^2$). Furthermore, assuming a mean absorber thickness of the c-Si wafers of $d_{c\text{-}Si} = 250\,\mu m$, one arrives at a total volume of crystalline silicon[2] of $V_{c\text{-}Si} = 1.65 \times 10^5\,m^3$. The energy required to produce c-Si wafers presently amounts to about 1,300 kWh/m^2 [4], which corresponds to about 4.3×10^{14} Wh for a 5 GW photovoltaic plant.

At the present time, the lifetime of such c-Si modules is considered to be around 30 years (2.6×10^5 h), which translates to a production rate of $V^*_{c\text{-}Si} = 15\,m^3$/day. This corresponds to the production of modules with an area $A^*_{mod} = 3 \times 10^4\,m^2$/day. The power input for a daily output of 15 m^3 c-Si amounts to about 1.7 MW. Here, we understand that this type of business will no longer be run by a small factory, but will rather resemble an industrial plant for mass production, as for tires, for chemicals, or for cars!

Furthermore, the average production power of a 5 GW photovoltaic plant of 4.3×10^{14} Wh within the 30 years of its lifetime yields about 1.5 GW. Consequently a c-Si photovoltaic power plant (under central European insolation) would pay back its energy needed for production after 9 years. Thin film photovoltaic modules (however, somewhat less efficient) are assumed to need substantially less energy for production (factor 0.1–0.2) and thus their energy pay-back time amounts only to few years or even less.

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[2]Including another 250 μm of powder produced by slicing the ingots, we end up with $d_{tot.\,mat.} = 500\,\mu m$ for the entire necessary material thickness.

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