Road Map
Renewable Energies Switzerland

An analysis with a view to harnessing existing potentials by 2050

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Executive summary

Establishing a sustainable energy supply for Switzerland is possible. However, it is neither a short-term nor an easily accomplished task. Indigenous renewable energy sources can offer a decisive contribution. This SATW publication indicates in how far this is achievable on the basis of technically exploitable potentials.
In many cases, the limiting factor is given not so much by actual existing potentials as by an economically justifiable speed of realisation, especially with regards to building renovation.
A supply relying mainly on indigenous sources of renewable energy by 2050 would require the combined development of the potentials presented in this study and realisation of the 2000 watt society which has been set as a strategic objective by the Swiss Federal Council.

The SATW

Who are we?

As a non-commercial and politically independent umbrella organisation, the Swiss Academy of Engineering Sciences (SATW) brings together individuals, institutions and specialist societies in Switzerland who are active in the engineering sciences, their application and their promotion. The SATW has around 240 individual members and 60 member organisations. Individual members are prominent personalities from the fields of education, research, business and politics.
The SATW is a member of the umbrella association «Swiss Academies of Arts and Sciences».

What do we want?

The SATW is committed to promoting technology at the service of society as a whole and furthering the understanding of technology. It thereby supports Switzerland as a site for research, education and production, as well as Swiss society, economy and culture.

What do we do?

The SATW stages events, publishes studies and periodicals, organises visits, takes a stand on current issues and supports the activities of other organisations.

Detailed information on the SATW is available under: www.satw.ch

Foreword

The production of oil and natural gas will soon reach its peak and then decline. The only question is whether this maximum will already be reached in ten years or only in thirty. Switzerland, like all industrialised nations, thus faces a profound restructuring of its energy supply.

In this situation, many hopes rest with a stronger harnessing of renewable energy sources. The *«Road Map – Renewable Energies Switzerland»*, compiled by the SATW Energy Committee, examines to which extent these hopes are justified if the technically exploitable potentials located within Switzerland are developed and tapped. The study shows that, with the road map's implementation, the supply of renewable energy forms could be doubled by 2050. The results are both sobering and encouraging.

It is sobering to learn that, should energy consumption remain stable at current levels, renewable energy sources, including hydropower, will only be able to satisfy a good one third of requirements. This situation is not improved fundamentally by a comparison with the energy perspectives currently being compiled by the Swiss Confederation: depending on the scenario, there remains a gap between supply and demand of 50 percent or more.

On the other hand, the situation is encouraging when viewed in combination with the vision of a 2000 watt society, which the Swiss Federal Council has set itself as a strategic target. In the event of the joint realisation of the road map and the 2000 watt society, three quarters of energy requirements could be satisfied based on indigenous renewable sources. An energy supply which is stable in the long term, and thus sustainable, therefore seems possible for Switzerland without resorting to futuristic scenarios such as fusion reactors or a hydrogen society powered by solar radiation.

The SATW is fully committed to the goal of a sustainable Swiss energy supply. It has already shown that the consumption of fossil energy carriers in Switzerland could be halved in the medium term without cuts in wealth. For reasons which are put forward in the road map, only a restructuring of our energy supply which is launched in the near future and spread over many decades is sensible from an economic perspective. Let us start out!

Prof Dr René Dändliker
President of the SATW

Prof Dr Andreas Zuberbühler
President of the SATW's Scientific Advisory Board

Renewable energy – a potential solution?

Current energy supply patterns cannot be sustained in the long run. Can renewable energies help avert the looming energy crisis? The present road map indicates to which extent such hopes are justified.

Today, over 80 percent of worldwide energy supply relies on coal, oil and natural gas. Consumption of these resources has been increasing steadily over the past years. The extent to which fossil energy carriers are being used cannot be sustained in the long term. In the cases of both oil and natural gas, it appears that production cannot keep up with demand. The fact that most fossil energy carriers are being produced in politically unstable regions is a further cause for worry. Western countries are thus facing critical dependencies.

Sustainability as a long-term objective

It is obvious that a sustainable energy supply can only be achieved with a profound change in current modes of energy production, transformation and use.

The use of fossil energy carriers is also problematic from an ecological point of view. The main issue here is the ever more clearly looming global climate change, which can be traced to increasing atmospheric concentrations of the greenhouse gas CO_2. Efforts are being launched at an international level in order to reverse this trend. The Kyoto Protocol, which Switzerland has also ratified, thus aims to reduce global emissions of six greenhouse gases, first amongst which CO_2, by around 5 percent compared to 1990 levels by the year 2012. Today however, the long-term shape of international energy and climate policy remains unclear.

In its strategy for a sustainable energy supply, drawn up in 2002, the Swiss Federal Council recommends aligning Swiss energy and climate policy with the targets of a 2000 watt society and per capita emissions of 1 tonne of CO_2 per year. In view of the fact that in Switzerland today, per year and per capita 5200 watt of power are being produced from primary energy and CO_2 emissions stand at over 6 tonnes, it becomes obvious that the set goals can only be achieved with a profound change in current energy supply, transformation and use. Efforts are required in three fields: firstly, primary energy deployed must be used more efficiently until it is used for the provision of energy services; secondly, energy supply must increasingly rely on energy sources with low levels of CO_2 emissions; thirdly, users must modify their patterns of behaviour.

Assessing implications

This report is concerned with the second potential for action, the development of energy forms with low carbon emissions. Next to nuclear power, all renewable energy sources fulfil this criterion. In Switzerland, only two of those are today being used to any notable extent, namely hydropower and wood. Other renewable energy sources however, such as wind, geothermal power, photovoltaics or further biomass, have been tapped only tentatively. Many expect these energy sources, often labelled «new renewables», to contribute significantly to the expected changes in energy supply.

With its *«Road Map – Renewable Energies Switzerland»*, the Swiss Academy of Engineering Sciences (SATW) aims to indicate to what extent these hopes are justified. The report documents the scope of the technically exploitable potential of indigenous renewable energy sources, how far it could reasonably be developed over the next 50 years and which impact this would have on the actual costs of energy.

Undoubtedly however, the development of renewable energy sketched here must be accompanied by a massive improvement of energy efficiency. The SATW study «CH50% – Halving Switzerland's Fossil Fuel Consumption» already showed in 1999 that, given energetically optimised buildings and means of transportation, this is possible without any reduction in energy services.

What exactly has been computed?

As a country possessing few raw materials, Switzerland has no direct access to fossil energy carriers but has to rely on their import. It can however make use in different fields of renewable energy sources available within the country. Three main forms are concerned:

> heat from heat pumps, solar thermal power, geothermal power and biomass;
> electricity from hydropower, wind power, photovoltaics, geothermal power and biomass;
> gas and liquid fuels extracted from biomass.

The road map outlines how the supply of renewable energy would develop over the next decades assuming that renewable energy sources technically exploitable potential within Switzerland is harnessed to a large extent. The possibility of renewable energy imports, such as biofuels, electricity from solar or wind power or solar-produced hydrogen, has been consciously excluded from these considerations.

For the first time, this report indicates how many installations would concretely need to be put in place over time in order to harness existing potentials, which investments would be required and which would be the consequences for the actual costs of heat, electricity and fuels. The comparison with existing demand scenarios makes it possible to reach certain conclusions regarding the possible contribution of indigenous renewable energy sources to Switzerland's long-term energy supply.

Changes over time

The road map is based on a dynamic model. This takes into account that installations display characteristic features which may evolve over time. These features include technical aspects such as an installation's average power resp. its annual energy production, its average life span, its transformation yield as well as the energy required for its fabrication, operation and disposal. The technically exploitable potential of a renewable energy source is linked to these features. It indicates the expected extent to which a renewable energy source can reasonably be harnessed from a technological point of view. What qualifies as technologically reasonable depends amongst others on the subjective assessment of experts. The potential is expressed in produced amount of energy or number of installations. Setting up the respective installation park should occur harmoniously, with an initially progressive growth, a phase of development and a period of saturation, as shown in figures 1 to 3 (see page 15). Overcapacities can thus be avoided and costs optimised.

Making use of expert knowledge

The model also takes into account economic aspects such as investment costs for the construction and costs for the operation of installations, and their decrease with growing market experience (learning curve). From these specifications, the model computes how many installations must be put in place every year, how many installations are respectively already in place, how much energy they produce and how large are the annual capital requirements needed to fund this development.

Any pronouncement on an evolution which unfolds over such a long period of time is bound to suffer from some uncertainties. The road map relies on the knowledge of experts working within the administration, scientific institutions and specialist associations as well as data published in the specialist literature. The data used has been compiled in cooperation with the Swiss Federal Office of Energy (SFOE), the Federal Energy Research Commission (CORE) and the Paul Scherrer Institut (PSI). The quality of the data available for individual energy sources has improved substantially over the past years. With the exception of geothermal power, the energy sources reviewed in the road map are already today being used to an extent which allows a more precise assessment of future developments.

An overview of technologies

In the following, the assumptions made in the road map for individual technologies aiming at the exploitation of renewable energy sources are described separately for each form of use. We respectively list the amount of energy produced in 2003 and the amount of energy produced in 2050 in the event of a full realisation of existing potentials, as well as the corresponding number of installations put in place, the investment costs per unit of power and the operating and actual costs per produced unit of energy.

An exception is made in the field of ambient heat production with heat pumps, wood heaters and solar collectors, for which corresponding values are given for the year 2070. Given that the integration of installations into existing buildings will often go hand in hand with complicated architectonic modifications, in this case potentials can only be tapped in rhythm with the rate of building renovation. A full realisation of existing potentials is thus not to be expected already in 2050 but only around 2070.

Heat pumps

Around 80 000 heat pumps had been installed in Switzerland by 2003, producing in total 1.4 TWh of heat for ambient heating and hot water. The energetic yield of present-day installations – as expressed by the annual coefficient of performance – averages 2.8. Recent measurements indicate that in the meantime, the annual coefficient of performance for new installations lies clearly above 3. This value should increase further over the coming decades. The road map assumes that five times as many heat pumps will be installed by 2070 than today, their average power doubling from currently 10 kW to 20 kW, as increasingly hot water requirements will be covered and larger buildings fitted with heat pumps.

The potential for heat production with heat pumps is estimated at 15.6 TWh. The limiting factor is given less by the availability of heat sources (air, earth, water) than by demand: in a few decades, building envelopes will be substantially better insulated, and the oil and gas heaters still in operation today will not all be replaced with heat pumps, but partly with wood heaters and solar collectors.

	2003	2070
Heat production [TWh]	1.4	15.6
Installations in place	80 000	400 000
Investment costs [Fr/kW]	1600	1200
Operating costs [c/kWh]	10.7	6.0
Actual costs [c/kWh]	17.9	10.6

Key figures of the production of heat with heat pumps

An important part of operating costs for heat pumps arises from the purchase of electric propulsion energy. The road map posits an average purchase price of 15 c/kWh. According to current knowledge, most heat pumps will still be operated electrically in 2070. The amount of electricity required is estimated at 3.9 TWh. However, these additional electricity requirements will be compensated at least partly by savings in the field of conventional resistance heaters, as these are replaced by different technologies.

Solar thermal power

Solar thermal installations, often called solar collectors, usually generate hot water for daily use. Often, they also simply generate warm air for ambient heating. Air collectors used for drying hay, which currently

	2003	2070
Heat production [TWh]	0.19	4.4
Installations in place	39 000	400 000
Investment costs [Fr/kW]	1600	1150
Operating costs [c/kWh]	4.2	2.7
Actual costs [c/kWh]	25.2	11.4

Key figures of the production of heat with solar collectors

dominate in terms of sheer number, were not taken into account in the road map in order to avoid distorting the attempted representation of induced industrial activity in the field of housing technology.

The average installation size will increase from 12 m² today to 18 m², the surface occupied by installations from 0.5 to 7 km². A multiplication by ten of the number of installations, in order to reach 400 000 by 2070, seems plausible in view of a current building stock of around 1.5 million buildings. The road map thus assumes a heat production potential of 4.4 TWh by 2070. The high number of installations to be newly fitted will have a positive impact on investment costs, as today's still largely manual production will be strongly automated.

Deep geothermal power

The technology used in Switzerland to harness deep geothermal power relies on the principle of deep heat mining (DHM). In addition, heat stemming from geological layers located close to the surface is used for heating purposes. This form of use is taken into account under the heading of heat pumps. Of all the transformation technologies devised to make use of renewable energy sources, DHM is the least technologically mature. The theoretical potential of DHM is significant, but no installations are in operation in Switzerland as of yet. A first pilot installation is currently being built near Basle.

	Wärme	Strom
Energy production [TWh]	2.4	2.1
Installations in place	Total 20	
Investment costs [Fr/kW]	2500	3500
Operating costs [c/kWh]	3.3	4.3
Actual costs [c/kWh]	5.4	6.3

Key figures of the production of heat and electricity from deep geothermal power in 2050

In view of the uncertain character of available data, the road map relies on a conservative estimate for 2050. In the final expansion, it should be possible to generate up to 6.9 TWh of electricity annually in Switzerland without depleting the resource of deep geothermal power.

Despite modest operating temperatures of less than 200 °C, the combination of electricity generation and waste heat recovery with corresponding long-distance heat distribution would appear to be the most economical solution for deep geothermal power. However, it remains debatable whether the construction of new long-distance heating networks is economically justifiable in view of buildings' markedly lesser heating requirements by 2050. Next to the combined production of heat and electricity, the exclusive production of electricity is also conceivable, in which unused heat would be discharged in watercourses or cooling towers. In this case however, the actual costs of electricity would be over twice as high. The road map makes the assumption of respectively 5 installations with a power of 40 MW producing either only heat or only electricity and 10 installations with a power of 50 MW producing a combination of heat and electricity.

Biomass

Of all renewable energy sources, biomass is the most heterogeneous. Biogenic waste, used wood, wood stemming from forestry activities, useful plants, agricultural residue or food remains can all be utilised. Exploitation technologies are just as diverse: combustion, gasification, fermentation. Biomass can be used to produce heat and electricity as well as gaseous or liquid fuels. In Switzerland, it is currently mainly used to generate heat and electricity. To a lesser extent, fuels are also produced from ethanol, rapeseed methyl ester and methane.

Profitability depends largely on the cost of the biomass. The scope stretches from compensations received for the avoidance of waste disposal costs, through cheap sawmill residues to costly energy crops. The fermentation of biogenic waste to obtain methane and humus is inexpensive and reliable. Biomass is used on a large scale in thermal plants and for the production of biofuels. The gasification of solid biofuels or more efficient combustion processes would open up even more diverse fields of application. However, these options are not yet technologically mature and are still relatively expensive.

As it is impossible to predict which will be the main field of application for biomass in 2050 resp. 2070, a simple assumption is made: one quarter of the existing potential at the level of unprocessed biomass (33 TWh of primary energy) is used respectively for the production of heat, electricity and liquid fuels. A last quarter is used for the production of gas which can in turn be used to generate heat or electricity, or as fuel.

Heat production from biomass

The production of heat from biomass (mainly wood) is widespread in Switzerland. Additionally, heat is produced from waste material in waste incineration plants and other combustion plants. In 2003, 3.0 resp. 2.2 TWh of useful heat were produced in this way in around 75 larger-scale installations. It is to be expected that the roughly 54 000 boilers installed today will increase to around 124 000 by 2070. Operating costs depend mainly on the cost of fuel.

	2003	2070
Heat production [TWh]	5.2	8.4
Installations in place	54 000	124 000
Investment costs [Fr/kW]	1500	1100
Operating costs [c/kWh]	11.2	9.1
Actual costs [c/kWh]	16.1	12.8

Key figures of the production of heat from biomass

Overall, a potential of 8.4 TWh ensues for 2070. The possibility of recovery of the waste heat which obtains during the production of electricity and gas and during fermentation is not taken into account. Still, it amounts to an annual 2 TWh of heat.

Electricity production from biomass

There are numerous ways to produce electricity from biomass. Depending on the technology, the biomass is first transformed into gas, fuel or heat and then, through turbines or motors, into electricity. In future, it is also conceivable that fuel cells will be used. Currently, electricity is already being produced on a large scale in 28 waste incineration plants.

The road map does not distinguish between electricity produced in thermal, gasification or fermentation plants. It assumes that the average yield can be increased from its current level of 30 percent to 45 percent. Operating costs are estimated at roughly 40 000 Swiss francs

	2003	2050
Electricity production [TWh]	0.78	3.8
Installations in place	580	2350
Investment costs [Fr/kW]	2500	2000
Operating costs [c/kWh]	13.6	9.3
Actual costs [c/kWh]	17.6	12.0

Key figures of the production of electricity from biomass

(2003) resp. 30 000 Swiss francs (2050) per installation. The cost of raw material varies depending on origin, from compensations received for the avoidance of waste disposal expenses to costs of up to 10 c/kWh. The study assumes average costs of 6 c/kWh.

Gas production from biomass

Biogas is produced by fermentation or gasification. The first method has been used in Switzerland at municipal level on an industrial scale for years through compogas and the production of landfill gas. Sewage gas is produced in sewage treatment plants and in agricultural biogas facilities. Gasification however is not yet fully mature as a technology, although on an industrial scale it holds the promise of a cost advantage in the exploitation of solid biomass in the form of wood. Today, the majority of biogas is used for the production of heat and electricity; the rest is injected into the gas network and used as fuel.

It is assumed that in future, next to numerous small-scale installations, large-scale installations with a power of a few 10 MW will also be realised. As a consequence, facilities' average power will increase sharply. The cost of raw material is decisive also for the production of gas. For biogas installations, biomass is available at close to no cost: farmers use their manure at no charge, compogas benefits from a compensation for the biomass taken on and landfill gas is also free, as it would otherwise have to be flared off. Sewage gas plant operators do not make any payment for biomass either, but rather receive a compensation for its disposal. As a consequence, the calculation relies on an average value for the cost of fuel of 1 c/kWh. By 2050, these costs should increase on average to 4 c/kWh, as not all biogas production can rely on such cheap sources. This will in particular be the case for large gasification plants.

	2003	2050
Gas production [TWh]	0.69	5.0
Installations in place	70	830
Investment costs [Fr/kW]	2000	1500
Operating costs [c/kWh]	10.0	11.7
Actual costs [c/kWh]	15.2	12.7

Key figures of the production of gas from biomass

Liquid fuel production from biomass

Two main forms of liquid fuels are extracted from biomass: biodiesel (mainly rapeseed methyl ester) and ethanol stemming from plant sugar. The production of rapeseed oil is already far advanced in Germany and ethanol is mainly produced in Brazil, in the United States and in France. The road map does not specify which technologies are used for the production of biofuels. They are well-tried abroad and can be implemented in Switzerland at relatively short notice.

	2003	2050
Fuel production [TWh]	0.021	5.8
Installations in place	1	50
Investment costs [Fr/kW]	2500	1500
Operating costs [c/kWh]	16.0	11.2
Actual costs [c/kWh]	21.7	12.5

Key figures of the production of liquid fuel from biomass

Photovoltaics

Photovoltaics is the direct transformation of solar radiation into electricity. Photovoltaic installations can be integrated into the building envelope, becoming part of the housing technology. However, the installations only produce electricity a small part of the time. It is furthermore not freely retrievable and can only be stored indirectly through the network.

The surface area potentially available for the production of photovoltaic power in Switzerland is limited mainly to building envelopes. Open air installations should remain the exception and are thus not taken into account. If we admit as a limiting factor the available roofing surface offering an adequate orientation to the sun, it should be possible to achieve an installed power of 14 000 MW. However, the limiting factor is given not so much by available surface as by the issue of integration into the existing electricity network, as in case of insufficient solar radiation, power must be compensated from other energy sources.

Network control thus becomes the critical factor of photovoltaics. The information required to correctly assess its potential is still lacking today. In particular, it remains unclear how the yields of photovoltaics correlate over time with those of other renewable energy sources.

For the road map, two scenarios have thus been considered:

> Scenario 1: Photovoltaics is developed to reach a total power of 2000 MW. In view of current control capacity and network technology, this quantity can still just be absorbed as variable power.

> Scenario 2: Photovoltaics is developed to reach a total power of 6000 MW. This scenario takes into account that new, freely retrievable sources such as deep geothermal power or biomass, as well as possible yields from water and wind power which complement each other over time, can contribute to smoothing fluctuations.

The assumed maximum potential of roughly 5.7 TWh corresponds to a roofing surface of 30 km^2, i.e. roughly 10 percent of total roofing surface available in Switzerland. The average power of photovoltaic installations should increase from around 12 to 25 kW; on one hand, implementation on a large scale will lead to an increased construction of large facilities, on the other hand the average yield per module will increase over the next 50 years from currently 13 to 21 percent.

Scenario 1	2003	2050
Electricity production [TWh]	0.017	1.9
Installations in place	1580	80 000
Investment costs [Fr/kW]	7500	2200
Operating costs [c/kWh]	5.7	3.4
Actual costs [c/kWh]	78.6	13.4

Scenario 2	2003	2050
Electricity production [TWh]	0.017	5.7
Installations in place	1580	240 000

Key figures of the production of electricity from photovoltaic power: in scenario 1, total installed power is developed until it reaches 2000 MW, in option 2 6000 MW. Investment, operating and actual costs are equivalent in both scenarios.

Wind power

Worldwide over the past years, wind power has experienced a development of unexpected magnitude. On exceptional sites abroad, electricity can already be produced at competitive prices. The actual costs of electricity have fallen faster than expected. In Switzerland, wind power remains almost untapped. It presents the advantage that the best conditions prevail during the winter semester. Wind power thus offers a good complement to hydropower and solar power.

If, for reasons of profitability, we confine ourselves to sites providing wind speeds of more than 4.5 m/s as a yearly average, as well as some security in planning owing to their location in built areas, we arrive at a potential of 1500 wind plants. Two types of installations can be

	2003	2050
Electricity production [TWh]	0.005	1.2
Installations in place	6	650
Investment costs [Fr/kW]	1900	1500
Operating costs [c/kWh]	6.7	3.8
Actual costs [c/kWh]	27.2	12.5

Key figures of the production of electricity from wind power

distinguished: wind parks producing a total of 1.2 TWh and individual installations on specific sites producing an additional total of 2.8 TWh of electricity per year. In agreement with the Concept for wind energy, drawn up for Switzerland in a broad process of consultation, only the potential of wind parks has been taken into account.

Hydropower

With an average expected production of 34 TWh, hydropower is without doubt the most well-used renewable energy source. However, its potential in Switzerland is almost exhausted. The present study concedes a possible growth of 3 TWh by 2050. It would stem partly from an improvement in the efficiency of the machines used (increase of average expected production by 2 TWh), partly from the development of mainly small hydropower stations (< 300 kW) by 1 TWh. Yet, stricter requirements relating to residual flows could curb this growth.

The road map assumes average actual costs of 6 c/kWh for large-scale hydropower and 11.6 c/kWh for small-scale hydropower. In the long run, the costs for the production of electricity from hydropower are determined by factors which partially compensate each other. The full amortisation of facilities and the use of more efficient installations will have a positive impact on actual costs. On the other hand, stricter requirements must be expected regarding residual flows. The road map thus assumes that real actual costs will remain constant over the period under consideration.

Large-scale hydropower	2003	2050
Electricity production [TWh]	34.0	36.0
Installations in place	500	500
Actual costs [c/kWh]	6.0	6.0
Small-scale hydropower	**2003**	**2050**
Electricity production [TWh]	0.3	1.3
Installations in place	1000	2000
Investment costs [Fr/kW]	1800	1800
Actual costs [c/kWh]	11.6	11.6

Key figures of the production of electricity from hydropower

Taking stock from an energetic perspective

The calculations indicate that the production of electricity, heat and fuels with renewable energy carriers could be increased significantly over the 50 years to come. However, this would imply considerable annual growth rates.

In how far can indigenously available renewable energy sources effectively contribute to Switzerland's energy supply by 2050, assuming they are developed to the extent indicated above? The model used in this study computes the temporal dynamics of this development at the level of individual installations put in place by form of use and technology. The following gives a graphic representation of the evolution of the amount of energy produced by these installations and the corresponding actual costs (see page 15).

	2003	2050
Photovoltaics	0.017	5.7
Biomass	0.78	3.8
Geothermal energy	–	2.1
Wind power	0.005	1.2
Small-scale hydropower	0.3	1.3
Large-scale hydropower	34.0	36.0
Total	35.1	50.1

Comparison of electricity production (in TWh) from renewable energy sources in 2003 and 2050. The values relating to photovoltaics are based on scenario 2 (development of installed power to 6000 MW). The values for hydropower correspond to average expected production.

Only little grey energy
With the exception of photovoltaics and heat pumps, the energy required for the construction, operation and disposal of installations is mainly not significant.

Energy required for the construction, operation and disposal of installations is not explicitly identified. In most cases, these requirements are low and would only reduce the graphs' clarity. Only the energy required for construction in the case of photovoltaics and the operating energy required by heat pumps stand out. In the final stage of expansion, while the latter allow the extraction of 15.6 TWh of renewable heat from the environment, this requires the injection of 3.9 TWh of electricity, thus reducing net energy production to 11.7 TWh.

	2003	2050
Heat pumps	1.4	11.3
Biomass	5.2	7.2
Solar thermal energy	0.19	3.4
Geothermal energy	–	2.4
Total	6.8	24.3

Comparison of heat production (in TWh) from renewable energy sources in 2003 and 2050

Electricity production

With the development outlined in the road map, by 2050 the production of electricity from renewable energy sources in Switzerland will increase by 15 TWh compared to current levels (figure 1). Taking into account electricity produced by existing hydropower stations, electricity production will amount to 50.1 TWh. With a share of 75 percent, hydropower will retain its position as leading supplier of electricity amongst renewable energies.

	2003	2050
Liquid fuels	0.021	5.8
Gas	0.69	5.0
Total	0.71	10.8

Comparison of gas and fuel production (in TWh) from renewable energy sources in 2003 and 2050

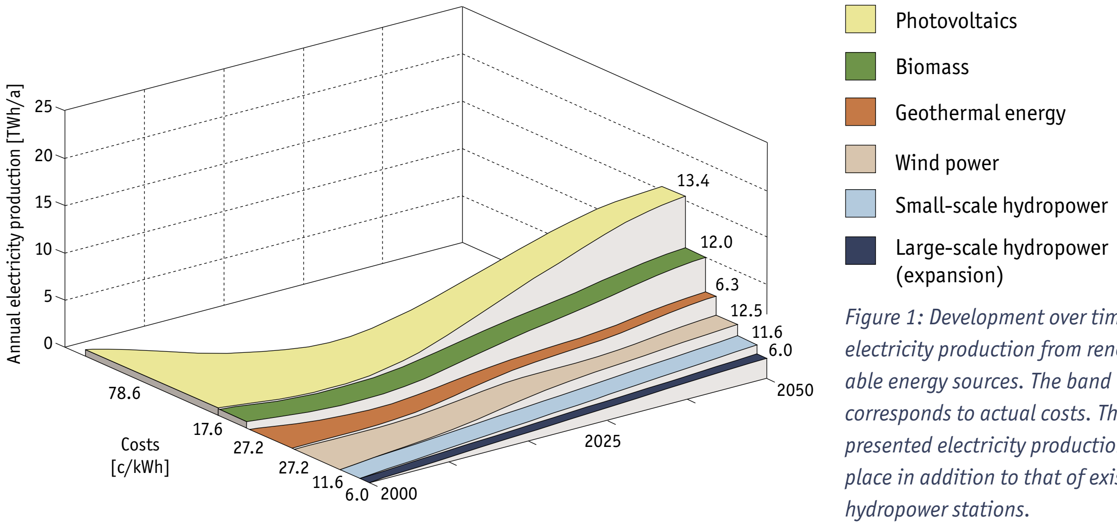


Figure 1: Development over time of electricity production from renewable energy sources. The band width corresponds to actual costs. The represented electricity production takes place in addition to that of existing hydropower stations.

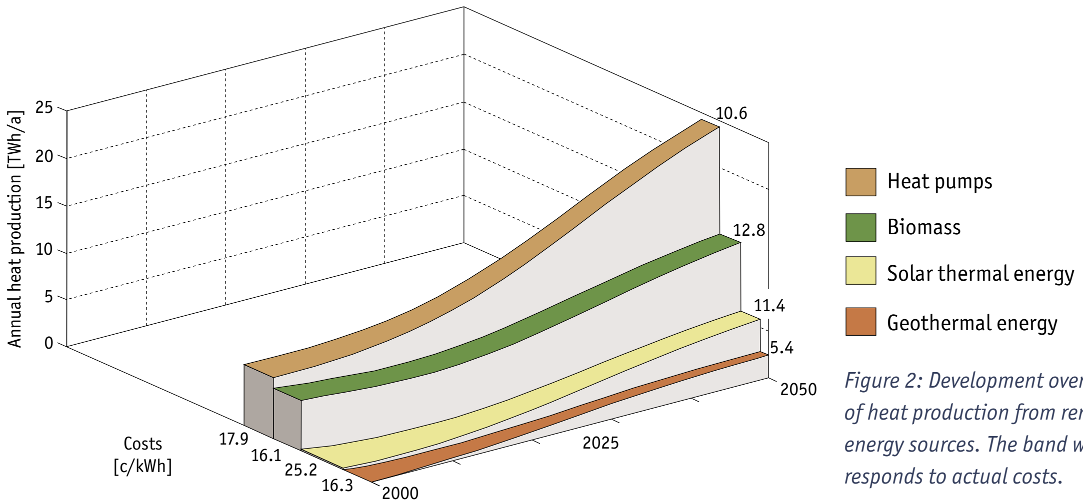


Figure 2: Development over time of heat production from renewable energy sources. The band width corresponds to actual costs.

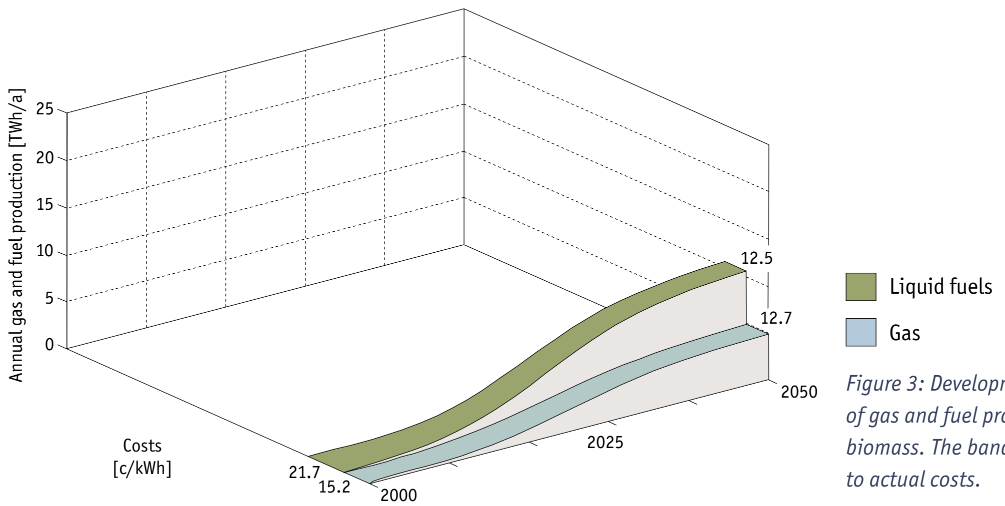


Figure 3: Development over time of gas and fuel production from biomass. The band width corresponds to actual costs.

Electricity produced from biomass, deep geothermal power, photovoltaics and wind power will contribute respectively at single-digit percentage rates. In the scenario of an expansion to 6000 MW, the contribution of photovoltaics as the most expensive option would amount to 11 percent at the end of the observation period.

Heat production

As mentioned above, a full realisation of existing potentials in the case of heat pumps, wood heaters and solar collectors is to be expected not already in 2050 but only around 2070. In order to allow for a comparability of values, it is assumed here that only three-quarters of potentials – and correspondingly of the number of installations put in place – will be realised by 2050.

An ambitious goal

The calculations show that the realisation of existing potentials is technically feasible over the 50 years to come. However, considerable efforts are required.

According to the road map, by 2050 the production of heat from renewable energy sources in Switzerland will thus increase by 17.5 TWh compared to 2003 and reach 24.3 TWh (figure 2). In the final stage of expansion in 2070, the production of heat from renewable energy sources will amount to 30.9 TWh. As regards the supply of heat, heat pumps and biomass contribute the largest share, followed by solar collectors and deep geothermal power. The 170 000 housing technology installations operating today will increase to 740 000 by 2050. In addition to around 430 000 heat pumps and biomass burners, 310 000 installations will be integrated in the building envelope for the production of heat.

Fuels

The production of chemical energy carriers from renewable energy sources is particularly attractive, as these can be easily stored and efficiently used. In 2050, a production of 5.8 TWh will be possible in the form of liquid fuels, the corresponding figure for gas is 5.0 TWh (figure 3). This latter value indicates the energy content of gas used directly as fuel or transformed into electricity or heat, as is already the case today with gas produced mainly in sewage gas plants. The production of gas indicated in the table is correspondingly taken into account in figures 1 and 2 in the initial value for biomass. In 2003, biogas was used directly as fuel to the mere extent of 0.006 TWh.

The long-term option of producing hydrogen from renewable energy sources has not been examined in any depth, as according to current knowledge it promises no significant contribution by 2050.

No bottleneck in sight

The calculations indicate that a full harnessing of existing potentials is possible by 2050, resp. by 2070 for the field of heat. Capacity limits in the construction and assembly of installations, energy expenditures and net capital requirements do not represent limiting factors. However, the calculations also indicate that the suggested development is ambitious and partly requires considerable annual growth rates.

Taking stock from an economic perspective

The development of renewable energy sources suggested by the road map is feasible also from a financial point of view. However, further delays in the realisation of this potential could prove problematic at an economic level.

The road map only models the evolution of energy production at installation level. The model thus computes actual costs at the «delivery clamp» to the customer resp. the respective network. Potential additional costs of integrating this energy into existing networks or such that remain to be built are not taken into account. Also not included are the additional costs of equalisation services in the event of fluctuations in the electricity supply from renewable energy sources, or the costs of distributing heat stemming from deep geothermal power.

The road map furthermore assumes that energy from renewable energy sources can be sold at respective actual costs, despite the fact that, at least today, these are in part substantially higher than those of non-renewable energy sources. It is thus tacitly implied that final consumers – be it voluntarily or owing to state intervention – will bear the additional costs of renewable energy sources by paying higher energy prices.

However, the production costs of renewable energy sources will fall sharply over the years to come, in accordance with the learning curve. In the field of electricity, in 2050 actual costs can be expected to lie between 6 c/kWh (large-scale hydropower) and a good 13 c/kWh (photovoltaics). Actual costs should also fall sharply in the field of heat production. In 2050, they should lie between 5 c/kWh (deep geothermal power) and 13 c/kWh (biomass).

Photovoltaics as the critical factor

The available data makes it possible to determine average actual costs for electricity stemming from renewable energy sources (figure 4). If the actual costs of electricity from hydropower, solar and wind power as well as geothermal and biomass facilities are passed on to clients following a mixed calculation, they will increase at most by 2 c/kWh by 2035, i.e. by about a third. Owing to the continuous decrease of actual costs, the surcharge in the mixed calculation would even drop to 1.5 c/kWh by 2050. Photovoltaic power plays an important role in this context. If photovoltaic power is developed only to a total level of 2000 MW rather than 6000 MW, average actual costs over the period under consideration will not increase by more than 1.5 c/kWh.

Some renewable energy sources are only available on

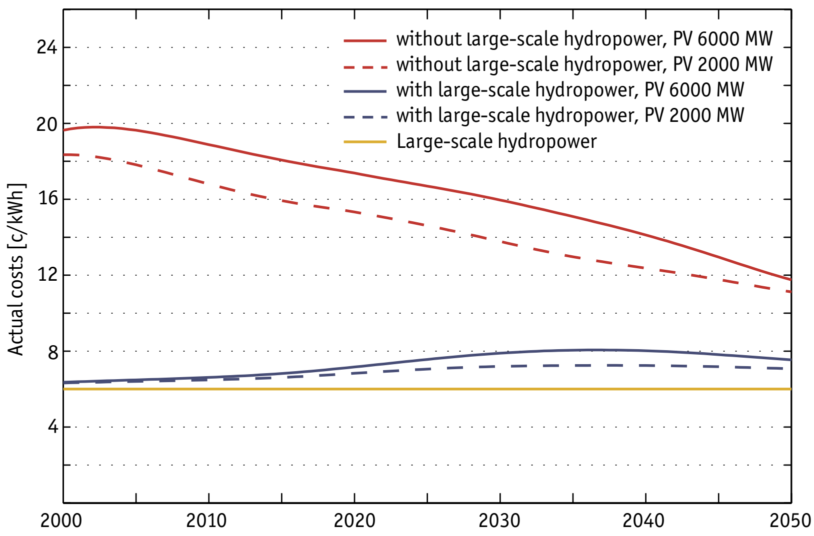
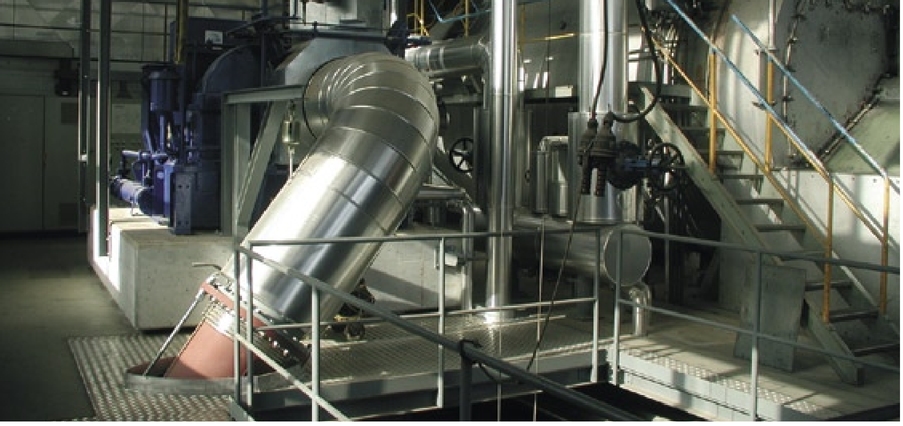


Figure 4: Average actual costs of electricity production from renewable energy sources. Plotted in red are the average actual costs of renewable energy sources yet to be developed. Plotted in blue are the average actual costs when this electricity is viewed in conjunction with electricity stemming from large-scale hydropower (orange).



an irregular basis. The cost of integrating these energy sources into the existing electricity network has not been examined. However, network costs, which in future should not fall significantly, already today account for two-thirds of the total actual costs of electricity, so that the increase of the price of electricity in the event of the road map's implementation should remain negligible.

Funding is no obstacle

The road map assumes that the development of renewable energies will not take place instantaneously. Annually required net investments thus remain within a sustainable scope for the economy as a whole.

As indicated by figures 1 to 3, the road map does not suppose an instantaneous development of renewable energy sources, but rather one stretching over half a century. The sum of annually required net investments, computed separately for each of the technologies, will increase continuously until about 2025. In the year of maximum expansion, they amount to around 500 million Swiss francs for option 1 with 2000 MW of final photovoltaic power and 750 million Swiss francs for option 2 with 6000 MW. After 2025, required net investments decrease again.

Avoiding overcapacities

At the level of the economy as a whole, funding should not be a limiting factor for the harnessing of renewable energy sources by 2050 in accordance with the road map. All the same, a more rapid development of renewables than outlined by the road map could prove problematic at an economic level. If the potential is developed very fast, overcapacities will obtain after the expansion in the concerned industry, as old installations do not yet need to be replaced. In view of this fact, it seems advisable not to delay investments in renewable energies but to press ahead. Otherwise, they would need to be developed all the faster at a later point, with undesirable consequences for producers.

		Number of installations in place 2003	2050	Max. installations to be put in place per year	Max. annual net investments [million Fr.]
Heat pumps		80 000	320 000 [1)]	15 000	65
Solar thermal power		39 000	310 000 [1)]	15 000	50
Deep geothermal power		–	20	1-2	20
Biomass	Heat	54 000	110 000 [1)]	2500	20
	Electricity	580	2350	100	25
	Gas	70	830	65	18
	Fuel	1	50	3	30
Photovoltaics 2000 MW		1580	80 000	3500	100
Photovoltaics 6000 MW		1580	240 000	16 000	450
Wind power		6	650	70	60
Small-scale hydropower		1000	2000	20	5

Development of renewable energy sources by 2050. Maximum annual net investments occur at different points in time for different technologies.

[1)] In the field of heat production, a full harnessing of potentials is to be expected only around 2070. In the event of the road map's implementation, at this stage respectively 400 000 heat pumps and solar thermal installations, as well as 124 000 installations for the production of heat from biomass, will have been put in place.

Actively seizing the opportunities

Switzerland has at its disposal a considerable renewable energy source potential. However, even if it should come to be fully harnessed, in future the country will still require non-renewable energy carriers in order to satisfy its needs.

The road map outlined here allows a number of conclusions which could have implications for long-term Swiss energy policy:

> Switzerland has at its disposal a considerable technically exploitable indigenous renewable energy potential. In the case of a full realisation of this potential, the production of useful heat, electricity and fuel from renewable energy sources will increase from currently 42.6 TWh to 85.2 TWh by 2050 and even 91.8 TWh in the final stage of expansion in 2070. Not taking into account large-scale hydropower stations, production will rise from 7.9 TWh to 49.2 TWh. However, provided energy consumption persists at its current level, even this growth would only make it possible to satisfy a good third of energy requirements from renewable sources. Should energy consumption continue to grow at the current rate, the additional renewable energy produced will not even match the increase in consumption. A reduction of our dependency on non-renewable energy carriers would be impossible to achieve.

A gap remains

> According to the new energy perspectives compiled by the Swiss Federal Office of Energy (SFOE) to the horizon 2035 with four scenarios (I - Business as usual; II - Heightened cooperation; III - New priorities; IV - Towards a 2000 watt society), should the road map be implemented, even in 2050 over half the energy consumed will still stem from non-renewable sources. Indeed, even in the most favourable scenario IV, which presupposes rigorous measures, energy consumption falls only by less than a third. On the other hand, even in scenario IV the perspectives assume that the use of renewable energies in Switzerland will amount only to roughly half of what the road map deems to be possible.

First problem area: electricity

> In the long run, the energy perspectives anticipate a growing electricity consumption. While electricity consumption does decrease by 5 percent by 2035 in scenario IV, its share of total energy consumption increases from around a quarter to a third. Even in the event of the road map's implementation, it will not be possible to supply Switzerland entirely with indigenous sources of renewable electricity by the middle of the century. In order to ensure an autonomous security of supply, a certain share of electricity production from fossil energy carriers or nuclear power will remain inevitable.

Requirements will keep growing
The Swiss Confederation's energy perspectives show that electricity consumption will keep increasing. A supply based exclusively on indigenous renewable energy sources is not realistic in the near future.

> The Federal Electricity Supply Act, which is currently the object of parliamentary consultations, plans to increase the share of renewable electricity production by 5.4 TWh by 2030. Set against the current



level of electricity consumption, this represents an increase of 10 percent from renewable energy sources. The road map indicates that these 5.4 TWh are feasible but already ambitious.

Encouraging prospects in the field of heat

> The highest rate of supply from indigenous renewable energies can be expected in the field of heat production. This is mainly due to the fact that by 2050 the building stock will have become much more energetically efficient. According to scenario IV, despite an increase of building surface area, heat requirements will fall by roughly 40 percent by 2035 compared with current levels. With the implementation of the road map, it should be possible to cover a good 40 percent of heat requirements with indigenous renewable sources by 2050. In the final stage of expansion in 2070, this share will even rise to over a half.

Dependencies in the transport sector

Even if energy demand in the transport sector should fall in the years to come, it will remain heavily dependent on fossil energy carriers in the long run.

Second problem area: mobility

> Next to electricity, the second notorious problem area of energy policy is the transport sector, resp. the energy required for our mobility, and more particularly the availability of liquid and gaseous fuels. Scenario IV of the Swiss Federal Council's energy perspectives predicts a decrease in energy demand in the transport sector by a third by 2035, meaning only 16 percent of these energy requirements can be satisfied with renewables. According to the road map, set against the level of consumption of scenario IV, one quarter of requirements can be satisfied from indigenous renewable sources, provided all gas produced from biomass is assigned to the transport sector. Even in the long run, transportation will keep depending heavily on the availability of fossil energy carriers, short of developing a radically new transportation system.

The 2000 watt society as a long-term objective

> If energy consumption in 2050 were in line with the 2000 watt society set as a goal by the Swiss Federal Council, roughly three-quarters of requirements could be covered by indigenous renewable energy sources. Only one quarter would still remain to be produced in a non-renewable form, probably from oil for liquid fuels, particularly in the field of air transportation, from natural gas, as well as from nuclear fuels for electricity stemming from nuclear power. Each additional TWh produced from indigenous renewable energy sources represents a step of 16 watt towards a sustainable energy supply. A sustainable energy supply which would rely mainly on indigenous sources of renewable energy is thus only possible given a far lower level of energy consumption than today. The development of renewable energy sources sketched here must thus go hand in hand with a massive improvement of energy efficiency.

Imports – an alternative?

> The option of importing renewable energy carriers has consciously been omitted from these considerations. Energy imports from renewable sources are partly cheaper than indigenous production. This is true in particular for biofuels and may also be so for so-called «green» electricity imports from wind power stations. The potential of renewable energy sources is thus rather higher than indicated by the road map.

Climate protection targets will not be reached

> The key indicator of the road map's ecological repercussions is the amount of avoided CO_2 emissions.



In order to be able to determine their volume, it is necessary to make an assumption regarding CO_2 emissions in the reference scenario in which the road map is not implemented. Two borderline cases are conceivable: either the totality of non-renewable electricity produced in Switzerland in 2050 will derive from power plants with gas/steam turbines (GST) operated with natural gas, or from nuclear power plants (NPP).

In the first case, CO_2 emissions will amount to roughly 50 million tonnes – provided energy consumption remains at its current level and a small shift from heating oil to electricity takes place. In the second case (NPP), CO_2 emissions in 2050 will amount to roughly 39 million tonnes. With the implementation of the road map, CO_2 emissions would stand at around 38 million tonnes in the case of GST, and roughly 32 million tonnes in the case of NPP. This implies a reduction by 24 resp. 18 percent, a notable contribution. However, it is not sufficient to achieve the aforementioned long-term climate protection target of 1 tonne of CO_2 emissions per capita, i.e. roughly 7 million tonnes in 2050. This is true even in the case of a decrease in energy consumption according to scenario IV of the energy perspectives combined with the implementation of the road map.

Urgent need for action

> The implementation of the road map leads to additional costs which can be deemed sustainable at the level of the economy as a whole. However, at the level of the individual decision-maker, renewable energy carriers remain expensive compared to conventional energy carriers. Even the scenario of a crude oil price of 100 dollars per barrel does not alter the situation fundamentally, as has been examined in the context of the energy perspectives. In the absence of accompanying political measures, the potential outlined in the road map will probably be realised only to a small extent, or with delays and under increased pressure, with undesirable economic consequences.

A political challenge

The road map does not specify which political framework conditions would be required or even only advantageous in order to fully harness the available indigenous renewable energy potential by 2050 in the manner outlined. It merely points out the technological and economic consequences which would arise should Switzerland decide to make use of existing possibilities. As the Swiss Confederation's energy perspectives foreshadow, a cluster of accompanying political measures will be required if the outlined road map is to be implemented. An active and effective energy policy is called for now and in the years to come in order to seize the available opportunity to ensure in the long term an adequate, economical and ecological energy supply based on renewable energy sources.

Data source

The present brochure is based on the study «Road Map für die erneuerbaren Energien in der Schweiz bis 2050 – Eine Analyse der Potenziale erneuerbarer Energien und ihrer Nutzung in der Schweiz», drawn up by Dr Markus Real, Zurich, on behalf of the SATW Energy Committee.

The following have collaborated on the production of this study:

> Simulations, methodology of the dynamic analysis and its interpretation: Dr Hans-Peter Bader, Ruth Scheidegger, EAWAG, Dübendorf
> Compilation of cumulated energy expenditures: Dr Mireille Faist Emmenegger, Dr Rolf Frischknecht, esu Services, Uster
> Scientific collaboration: Dr Andreas Gut, Swiss Federal Office of Energy, Berne; Prof Dr Alexander Wokaun, Paul Scherrer Institut, Villigen
> Graphs: Thomas Bosshard, ETH Zurich

On the basis of internal discussions with further experts, the SATW Energy Committee arrived at slightly divergent results for some of the relevant values.

Further reading

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Glossary

- **Actual costs**
  Yearly production costs of a production facility or installation (set against the average net amount of energy produced). They are computed from the sum of operating costs and capital costs (yearly depreciation and interest payments) divided by the net amount of energy produced. Actual costs do not take into account profits.
- **Investment costs**
  Set-up costs of a production facility or installation (set against the unit of power). These include costs for the installation's planning, construction, and putting into operation.
- **Net energy**
  Yearly amount of energy produced by an installation minus required energy expenditures for replacement parts and operation.
- **Net investments**
  Yearly capital requirements needed for the development and renewal of the installation park minus proceeds from fully depreciated installations which have not yet reached their life span. It is assumed that proceeds are fully reinvested.
- **Operating costs**
  Yearly expenditures required for the operation of a production facility or installation (set against the average amount of energy produced). Typically, these include payroll costs, the potential replacement of installation parts, fuel resp. auxiliary energy (e.g. electricity for heat pumps) or duties for rights of use of a resource (e.g. water rights).
- **Road map**
  Depiction of an optimised path for the development of renewable energy's technically exploitable potential.
- **Technically exploitable potential**
  It indicates the expected extent to which a renewable energy source can reasonably be harnessed from a technological point of view. What qualifies as technologically reasonable depends amongst others on the subjective assessment of experts. The potential is expressed in produced amount of energy or number of installations put in place.

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