Renewable sources of energy

Contents

1. Scope

In addition to finite deposits of fossil and mineral fuels such as oil, gas, coal and uranium, the earth also offers various natural, auto-regenerative - or renewable - sources of energy that derive from sun **insolation, geothermal activity and gravitational forces**.

Theoretically, the **global supply of energy** from such renewable sources by far exceeds the earth's present **total energy demand**. The supply of energy is subject in part to pronounced technical and economic utility limitations, e.g., the **disparity** between the temporal/spatial demand for energy and the actually available supply of renewable energies, and the latter's modest power density compared to conventional energy vehicles.

The main renewable energy (RE) sources are:

1. Insolation, i.e., the direct radiant energy of the sun (made useful by collectors, solar cells, etc.)

2. Energy obtained from biomass; biochemical energy of photosynthetic products; made useful by

- burning (of wood, straw, etc.)
- gasification (of wood, etc.)
- anaerobic digestion (= biogas)
- alcoholic fermentation

3. The kinetic energy of wind

4. The kinetic energy of moving water:

- low-pressure systems
- high-pressure systems
- micro-hydropower plants
- tides, waves, ocean currents

5. Miscellaneous

- geothermal energy
- thermal energy deriving from differences in seawater temperature
- osmotic energy deriving from concentration gradients between saltwater and freshwater.

With a view to the proper and adequate sizing and, hence, limitation of the environmental consequences of renewable energy systems, the energy consumers' options for the **conservation and rational use of energy** should always be given full consideration, whereas boundary conditions in the form of prices, tariffs, etc. are major factors.

The environmental impacts resulting from utilization of the following renewable sources of energy are dealt with in this brief:

- solar energy (heat and photovoltaics)
- energy from biomass
- wind energy
- hydropower
- geothermal energy.

To the extent deemed relevant, other renewable sources of energy are dealt with in other briefs.

With regard to the general environmental consequences of energy systems and to the supradisciplinary aspects to be considered in connection with the planning of energy policy and energy economics projects, the reader is referred to the environmental brief Overall Energy Planning.

2. Environmental impacts and protective measures

The utilization of energy, no matter what the source, is bound to have certain environmental consequences (land consumption, pollution, ...) that need to be identified and evaluated, preferably in advance.

2.1 Solar energy

The use of solar energy via collectors or photovoltaic systems places no immediate material burden on the environment. However, the collector system can be expected to contain a **heat transfer medium** (fluid), the escape of which could result in pollution. The acceptable media include such readily degradable substances as propylene glycols. Noxious additives serving as preservatives should be replaced by less harmful alternatives (carboxylic acid).

The use of solar cookers involves the **danger of blinding**, and solar energy collected by solar cells and stored in batteries demands proper handling and appropriate disposal of the spent batteries. The materials used for the battery case, as well as the hydrochloric acid and lead contents, can be recycled in suitable facilities.

Land consumption for small-scale systems can be avoided by installing them on roofs and facades. Well-considered integration can prevent optical/aesthetic impairment, and annoying reflections can be diminished by lumenizing and/or delustering.

With the exception of **reduced reflections**, no such measures can be applied to large-area systems. Consequently, optical/aesthetic expectations may stand in conflict with other natural surface potentials (soils for agricultural production, protection of species and biotopes; unless, of course, the site in question is located in the desert).

Depending on the local situation, the **shading and altered albedo** resulting from large-scale installations can affect the flora, fauna and microclimate (evaporation rates, airflow, temperature).

Solar cells and various collectors have a **substantial space requirement** relative to the amount of energy produced (per 100 MW: ~ 1 km² for solar cells and ~ 3 km² for solar-thermal power plants, compared to ~ 0.4 km² for hard-coal power plants).

Additional environmental impacts derive from the manufacture of **materials** used in the production of collectors and solar cells. Steel, copper and aluminum, all of which are used frequently, cause environmental problems in the form of emissions, i.e., particulates, fluorine compounds, solid and liquid waste and high levels of energy consumption, particularly for aluminum.

Some rare and **toxic metals** such as cadmium, arsenic, selenium and gallium used in solar cells are mildly pollutive at the processing stage (wastewater, exhaust gases). These substances are characterized by high chemical stability, and the environmental risk remains confined to the production site. Thus, adequate monitoring and safety measures can minimize the risk; cf. environmental brief Non-ferrous Metals.

2.2 Biomass energy

Used as a substitute for metal, cement, plastic and diverse other raw materials, biomass can help reduce the energy expenditures for processing and manufacturing such materials.

In the present context, however, our interest in biomass is limited to its being a source of energy.

Significant utilization of biomass presupposes that the biomass cycle of growth and extraction remains essentially intact, i.e., that the biomass source (a forest, perhaps), is always allowed to adequately regenerate.

2.2.1 Burning

The burning of biomass (wood, straw, dung, etc.) liberates **pollutants** -

– from the fuel and the combustion air
– or which form as a result of incomplete combustion [CO, tar, soot and hydrocarbons, including carcinogenic polycyclic aromatic hydrocarbons (PAH)].

The main cause of emission problems with biomass is **incomplete combustion**. The following measures can help achieve **complete combustion**:

Combustion plant

– sufficiently large incinerator
– sufficiently hot combustion chamber

Those conditions are inherently satisfied by systems equipped with prefiring chambers or for bottom firing.

Fuel conditions

– use of dry fuel (< 20 % wood moisture).

Mode of operation

– full-load operation
– uniform fuel supply.

The exhaust gases, particularly in the case of straw, contain large amounts of solid particulates; large-scale systems therefore should include appropriate cyclone separators or filters.

On a country-specific basis, **biomass can cover as much as 90 % of the overall demand for energy**. As a rule, wood, dung and straw are burned in **open fires** from which the aforementioned pollutants escape and can be inhaled by the users (primarily women and children).

This can amount to a formidable **health hazard**, particularly because of the carcinogenicity of polycyclic hydrocarbons. In addition, respiratory ailments can also result from such exposure.

The use of stoves with some form of chimney substantially reduces the indoor smoke nuisance and improves the combustion efficiency, thereby reducing fuel consumption and, hence, emission levels.

The **use of straw and dung as fuel** can lead to conflicts concerning agricultural production and the sustenance of soil fertility due to **loss of nitrogen and reduced humification**, because what has been burned cannot be returned to the soil. In some climate zones, using the ashes as fertilizer can cause a dust-evolution problem.

From an ecological standpoint, the use of **scrap wood and various forms of wood residue** calls for a somewhat sophisticated frame of reference: while tending felling can be both ecologically compatible and advisable, the safe extent of **wood removal from forests** and plantations depends on the climate, the soil conditions and the vegetation. The removal of wood residue impacts the nutrient cycle, humification, microflora and microfauna. This applies as well to large-scale stump-grubbing, which also makes the ground more **susceptible to erosion**.

Long-term natural wood production does not satisfy the "firewood criteria" of easy, short-term availability. **Agroforestry projects** involving certain harmonized plant species in certain spatial arrangements designed to make the individual species and combinations serve different functions (shading, soil amelioration, shelterbelting, improvement of water regimen, mulching, fuel, food/fodder, starting material), are able to more quickly satisfy fuel requirements by reason of brief rotation periods. Such - noncentralized - configurations facilitate the gathering of wood while abating environmental burdens in connection with road transport and helping to bridge over fuel shortages.

Intensive (energy farming) techniques based on fast-growing combustibles treated with high doses of pesticides and fertilizers can **pollute, i.e., eutrophize, surface waters** due to nutrient loading, possibly in combination with erosion, a loss of diversity, and health hazards emanating from residual pesticides. The use of machines on sensitive ground (marginal soils) can induce erosion; cf. environmental brief Forestry.

Large-scale felling of trees (= land clearing) affects the water economy and microclimate, is harmful to flora and fauna, and can cause erosion, the extent of which depends on the type of soil, the climate and the angle of slope.

If cleared land is not appropriately reafforested, or if the soil is overused for a prolonged period, both the soil and the water regimen may sustain irreversible damage.

Any attempt to substantially expand fuelwood production without **integrating the effort into the general agricultural scheme** can generate conflicts over space requirements for food production; cf. corresponding environmental briefs on agriculture, such as Plant Production, Forestry etc.

2.2.2 Gasification

As a rule, any gas extracted from biomass by such means as pyrolysis is used as fuel, either for heating purposes or for driving gas-fueled power generators.

While the environmental effects of fuel extraction from biomass are dealt with in section 2.2.1, additional ecological impacts can derive from:

– carburetion (accidents, deflagration);
– the gas itself (accidents, fire, poisoning due to leaks);
– wastewater from gas scrubbing;
– carbonization residue (ash, tar);
– combustion emissions (exhaust, cooling water, lubricant).

Generator gas obtained from large plants (as opposed to small wood gasifiers, e.g., for tractors) should be cleaned and dedusted prior to use. The **wastewater** from gas scrubbing can be expected to contain ammonia, phenols, perhaps even cyanides and potentially carcinogenic polycyclic aromatic hydrocarbons (PAH). Consequently, they cannot be disposed of freely. To the extent possible, the incidental **tars and oils** should be returned to the gasification process. In addition to the mechanical extraction of solids, e.g., in a settling basin, the effluent can be put through a biological clarifying plant in which phenols are digested by suitable strains of bacteria.

Solid residue from the gasification process is usually heavily polluted and therefore **problematic** with regard to its **disposal**. The **harmful-substance contents** require case-by-case determination, because they vary according to the raw material in question and the process employed.

The **exhaust** from generator gas combustion may also require treatment, depending on the quantity involved and its pollutive load. It is likely to contain oxides of nitrogen, PAH's, carbon monoxide or soot (plus negligible amounts of sulfur dioxide). The NOx and hydrocarbon contents can be extensively decomposed with the aid of **catalytic converters**.

2.2.3 Biogas

Biogas resulting from **anaerobic bacterial fermentation of biomass** consists primarily of **methane** (principal component), **carbon dioxide, carbon monoxide** and small amounts of **hydrogen sulfide**. Small biogas plants provide fuel for cooking, lighting, etc., while large-scale facilities can produce enough biogas for fueling gas motors.

Accidents can occur when a slurry pit or a fixed-dome digester has to be entered for cleaning (**danger of asphyxiation**).

Since hydrogen sulfide has **toxic** effects of humans, corrodes materials, and forms sulfur dioxide in the combustion process, its removal should be given due consideration. However, the precleaning process is rather complicated and generates end products with a pollutive potential. The chemicals used for cleaning biogas (e.g., iron oxide), as well as their reaction products (mixture of iron oxide and sulfur) demand proper storage, use and subsequent disposal.

Whereas biogas often requires interim storage, appropriate pertinent **safety standards** must be heeded (danger of poisoning, fire, explosion); cf. environmental brief Petroleum and Natural Gas.

The raw material may contain **toxic heavy metals** that are prejudicial to health. While such constituents (deriving from polluted soil) remain unaffected by the digestion process they nevertheless should be monitored (tested for). And while the digestion process does not kill off all pathogens and worm ova, the digested sludge nonetheless counts as safe and benign from the standpoint of epidemic control. Used improperly, its high nitrogen content can **emburden both surface water and groundwater**. Thus, the use of biosludge as a fertilizer must be properly timed (availability for plants), effected with suitable equipment, and applied in accordance with the soil's nutrient reserves.

Considering methane's relevance as a greenhouse gas, its collection and combustion is ecologically advantageous as long as it is being generated by anaerobic digestive processes.

2.2.4 Biofuels

Various technical processes are available for deriving oil and alcohol from biomass and using them as **substitutes for conventional fuels**.

The cultivation of biomass as a raw material for obtaining fuel by alcoholic fermentation (e.g., of sugar cane) or by extracting oil from soybeans stands in direct competition with foodstuff farming. Large **monocultures** involving high levels of fertilization and pesticide spraying have environmental impacts of the kind discussed in section 2.2.1; cf. environmental brief Plant Protection.

The following environmental loads result from the **production of ethanol and oil**:

– **exhaust gases** deriving from the provision of process energy (e.g., distillation, burning or refining of crude oil) - cf. section 2.2.1;
– **carbon dioxide** as a product of fermentation;
– nontoxic but very **pollutive organic sludge and wastewater** (slops) from ethanol production, all containing large amounts of nitrogen-phosphorus and potassium components.

The **slops**, or distiller's wash, can serve as a fertilizer or fodder additive. If it contains enough residual sugar or starch, it is suitable for fermentation, i.e., biodigestion.

The biogas yield can serve as a substitute for part of the conventional process energy, while the organic substances remaining in the effluent must be decomposed in a clarifying plant.

The production of alcohol is very **energy-intensive**.

The **use of ethyl alcohol (ethanol) as a fuel additive** in internal-combustion engines produces relatively low pollution in the form of NOx, CO, soot and simple hydrocarbons, but is accompanied by certain aldehydes, some of which are carcinogenic.

Motors fueled by alcohol alone should be specially tuned and optimized in order to minimize harmful emissions. **Catalytic converters**, for example, reduce the aldehyde emission levels to that of gasoline engines. Compared to gasoline/petrol, ethyl alcohol contains practically no carcinogenic polycyclic hydrocarbons.

Like alcohol, **biomass-base oil for diesel engines** gives off no sulfur or lead but some amounts of soot, simple hydrocarbons and particulate emissions. **Soot filters** are conditionally suitable for cleaning the exhaust gases.

2.3 <u>Wind energy</u>

Even large wind power plants have **modest environmental impacts**. Their material and space requirements are also relatively modest. The manufacture of some steel and plastic components, however, does involve certain environmental problems.

The following substantial environmental problems arise in connection with their operation:

– noise;
– landscape impairment;
– danger of accidents due to rotor-blade detachment;
– electromagnetic interference;
– negative effects on fauna, birds in particular.

How much **noise** is produced depends on how fast the propellor is rotating. The faster the speed of rotation, the louder the noise.

Old aerogenerators have been known to produce sound intensities on the order of 130 dB(A). Small wind generators tend to make more "wind" noise than running noise. New facilities have aerodynamically optimized blades and encapsulated generators-cum-transmissions that minimize the noise nuisance. Nevertheless, a minimum distance of roughly 100 meters should be maintained between wind generators and residential areas. There is, of course, always the possibility that the safe clearances designated at the planning stage will eventually be transgressed by uncontrolled settlement (squatting).

Impairment of the landscape is unavoidable. The degree of impairment depends on local circumstances, including the intensity of wind-power utilization. Wind parks do more to impair the landscape than individual plants. Especially large aerogenerators with metal motors tend to **disrupt natural electromagnetic fields** and interfere with radio reception. Modern wind power plants have fiberglass rotor blades and therefore cause no such interference.

The **danger of accidents** attributable to rotor-blade detachment can be minimized, if not precluded, by routine inspections and maintenance, plus adherence to the appropriate safety clearances.

2.4 Hydropower

Hydropower is the by far the most important renewable source of energy. The incidental reservoirs often serve other, additional purposes such as irrigation and the supply of drinking water.

The harnessing of hydropower entails substantial intervention in the environment (land consumption, altered hydrological regimen, etc.). Due to the importance of hydraulic engineering with respect to the environment, and with deference to the vast experience that has been accumulated in connection with such facilities, a separate brief has been devoted to that sector.

2.5 Geothermal energy

Geothermal sources of energy include:

– warm and hot water in deep-reaching joint systems of crystalline rock formations or deep-lying groundwater stories within expansive sedimentary basins,
– hot-water and steam occurring deep within structurally disturbed zones or in regions marked by current or recent volcanic activity,
– exploitation of geothermal energy according to the dry hot rock process (DHR technology presently under development).

DHR technology aims to establish artificial heat-exchange surfaces in hot rock (with temperatures > 200°C) from which geothermal energy can then be extracted by pumping water into and back out of the artificial hot-rock joint system. Despite substantial research funding to date, however, the method's economic feasibility has not yet been established.

The environmental impacts of exploiting geothermal energy depend on the concrete situation. **Environmental burdens** can result from entrained pollutants (various salts, sulfur compounds, arsenic, boron) and gases in the geothermal fluids. In modern geothermal facilities the spent (cooled-down) fluids and their entrained pollutants are pumped back into the ground, preferably to a point below the pay zone of the occurrence, while the incidental gases are released to the atmosphere.

The extraction of geothermal fluids, particularly in dry-climate regions, can negatively influence **near-surface groundwater stories** and, hence, their utilization (potable water, irrigation) by causing the groundwater table to recede (phreatic decline).

Sustained use of a particular geothermal reservoir can lead to gradual and extensive **subsidence** and frequent consequential damage to railroads, highways, power transmission lines and, particularly, the pipelines through which the geothermal fluids are pumped from the wells to the power plant/user. The local **hydrological situation** can be substantially influenced and modified by attendant phenomena such as the diversion of streams and rivers or even the formation of lakes in ground depressions.

The **space requirements** of geothermal installations (wells, pipelines) are quite modest - so much so that such facilities hardly interfere with agricultural utilization of the surrounding land.

The drilling of wells in a geothermal field is somewhat hazardous in that unforeseen eruptions of steam can occur without notice and then take weeks or even months to get under control. In the meantime, the environment may have become substantially contaminated by impurities in the steam.

3. Notes on the analysis and evaluation of environmental impacts

The main environmental consequences of renewable energy systems are the **consumption of land area** and the **loss of plant and animal species and biotopes**. Biomass utilization also involves **solid waste, wastewater and air pollution**.

The environmental consequences of renewable energy systems can be limited in quantity, but normally require qualitative analysis with due regard for avoidance effects (e.g., CO_2 emissions) in comparison with nonrenewable energy sources. To evaluate the environmental impacts of any such system, one must begin with an analysis of the biotic (flora and fauna) and abiotic (water, soil, air) ecological factors. For the biotic domain, mapping and charting activities are necessary. For the abiotic range, water, air and soil samples should be analyzed according to standard techniques such as those described in DIN/EN and ISO standards, NIOSH standards, guidelines of the Association of German Engineers VDI, WHO recommendations, etc.).

The **evaluation of environmental consequences** is a deficitary matter in that, for example, no limit values can be quoted for the loss of animal species, biotopes, etc. Nor do any **generally recognized standards of evaluation exist** - quantitative or otherwise - for landscape impairment. The **criteria** need not always be as unequivocally quantifiable as "rarity" (e.g., as defined by **international conventions** within the pollutants' sphere of influence); it is also difficult to attach a particular value to consumed land area with allowance for alternative uses. For the abiotic domain, though, certain limit values and recommendations can be enlisted in connection with various types of pollution (wastewater, exhaust, noise).

To the extent available, **effect-specific reference/limit values** should be consulted for evaluating immissions (airborne pollutants, noise, ...) as a means of anticipating the sensitivity (reaction) of existing and planned forms of utilization (housing, farming) to the projected impairment.

For all forms of renewable energy utilization, the importance of immissions and pollutant levels increases along with the size of the project.

In connection with the extraction of energy from biomass, any solid substances that are re-utilized instead of being treated as waste count as a positive effect that must be given due consideration.

4. Interaction with other sectors

If a planned renewable energy system will involve material emissions, the local prior load must be determined in advance of the project's implementation (e.g., condition of recipient water in conjunction with wastewater-producing processes).

In addition to the effects of renewable energy utilization listed in section 2, such **secondary effects** are also important. Apart from the project's consequences for the basic needs of certain sections of the population, its possible impacts on agriculture, water supplies, transportation and diverse aftereffects must also be accounted for (whereas allowance must be made for the fact that improving the supply of energy to or within a given region can have practically identical consequences for the sectors in question):

– The loss of farmland alters the food market structure and/or necessitates the agricultural utilization of formerly more or less "virgin" areas. For additional information, the reader is referred to the environmental briefs on agriculture (e.g., Plant Production).
– Any more intensive use of water resources naturally involves higher rates of water consumption, larger volumes of wastewater and, hence, changes in the water regimen. That, in turn, affects the soil, the microclimate, the composition of the microsystem, and the hygienic situation (salinization, spread of pathogens; cf. environmental briefs **Rural Water Supply, Rural Hydraulic Engineering Large-scale Hydraulic Engineering, Water Framework Planning.**
– Increased traffic due to transportation in connection with large-scale renewable energy applications (or simply attributable to an improved energy supply situation) necessitates more and better traffic infrastructure. Its provision, in turn, has primary and secondary development effects; cf. environmental briefs **Road Traffic, Transport and Traffic Planning**. The general environmental impacts of renewable energy exploitation systems are discussed in the environmental brief **Overall Energy Planning**.

5. Summary assessment of environmental relevance

This environmental brief summarizes the environmental consequences of renewable energy sources. Such consequences include gaseous and liquid emissions, solid wastes, noise evolution, use of sensitive materials, land consumption and other forms of impairment.

The renewable-energy utilization options involving **little or no replacement or decomposition of material** (solar, wind) and, hence, fewer direct consequences for the environment are deserving of preferential treatment.

The fact that long-term sustained use of renewable energy sources can fit neatly into the natural biochemical and energy cycles produces a situation in which combustion and digestion processes (wood, straw, biogas, alcohol), unlike those involving fossil fuels, **add no carbon dioxide to the atmosphere**, because the amount emitted is offset by the incorporation of equal amounts into the *regeneration* of biomass. In other words, biomass enables the CO_2 - neutral generation of energy.

On the other hand, again unlike fossil fuels, the **continuous renewal process of biomass** as an energy vehicle ties up land area, i.e., soil, that otherwise could be put to some other or additional use, e.g., for agricultural production or agroforestry.

Land consumption is unavoidable. Accordingly, valuable ecosystems must be protected - *instead* of simply being exploited as a renewable source of energy.

As long as the requisite facilities are properly maintained and serviced by skilled specialists, and as long as the operating personnel is well-trained, the use of renewable energy sources poses little **danger of accidents**.

Like most finite sources of energy, the majority of renewable energy sources can be exploited both on a large, centralized scale as well as through **small, noncentralized facilities**. Some renewable sources of energy (e.g., solar cells, solar collectors, biogas, wind power) are inherently suited to noncentralized forms of energy generation, particularly in connection with energy supply and development strategies for rural, village-level and regional development projects involving little or no transport costs. Such constellations help minimize energy conveyance losses and avoid such secondary environmental problems emanating from the socioeconomic ramifications of centralized development strategies as urbanization, rural-urban drift and their consequential effects; cf. environmental briefs Spatial and Regional Planning, Overall Energy Planning, Planning of Locations for Trade and Industry.

6. References

AKN Reddy: Rural Technology, Bangalore, 1980.

Albrecht, Buchholz, Deppe u.a.: Nachwachsende Rohstoffe, Bochum, 1986.

Bonnet, D. u.a.: Nutzung regenerativer Energien, Handbuchreihe Energie, Bd. 13, Cologne, 1988.

Bundesgesundheitsamt (German Federal Health Office): Vom Umgang mit Holzschutzmitteln, Berlin.

Bundesminister für Forschung und Technologie (German Federal Minister of Research and Technology) (Ed.): Expertenkolloquium "Nachwachsende Rohstoffe, Band 1 und 2, 1986.

EC-Council Directives relating to clean-air standards.

Edelmann, Fawre, Seiler, Woschitz (Ed.): Biogas-Handbuch, Aarau, 1984.

Fleischhauer, W.: Neue Technologien zum Schutz der Umwelt, Essen, 1984.

Fort, V.: Environmental Soundness, Proceedings of a Workshop on Energy, Forestry and Environment, Bureau for Africa, Agency for International Development, 1982.

Gadgil, M.: Hills, dams and forests; Some field observations from the Western Ghats, AKN Reddy, 1980.

Gieseler, G., Rauschenberger, H., Schnell, C.: Umweltauswirkungen neuer Energiesysteme, Dornier System/Bayerisches Staatsministerium für Landesentwicklung und Umwelt, March 1982.

Hartje, V.J.: Umwelt- und Ressourcenschutz in der Entwicklungshilfe: Beispiele zum Überleben? Frankfurt, New York, 1982.

Kannan, K.P.: Ecological and socio-economic consequences of water-control projects in the Kuttanad region of Kerala, AKN Reddy, 1980.

Kaupp, A. und Goss, J.R.: Small-scale Gas Producer-engine Systems, Braunschweig, Wiesbaden, 1984.

Kleemann, M.; Melіß, M.: Regenerative Energiequellen, Berlin 1988.

Lehner, G. und Honstetter, K.: Solartechnik, Ullmanns Encyklopädie der technischen Chemie, Band 21, Vienna, 1982.

Menrad, H.; König, A.: Alkoholkraftstoffe, Vienna, 1982.

Meier, P.: Energy Systems Analysis for Developing Countries, Berlin, 1984.

Montalembert, de, M.R.: The forestry/fuelwood problem in Africa and its environmental consequences, Proceedings of a Workshop on Energy, Forestry and Environment, Bureau for Africa, Agency for International Development, 1982.

Osterwind, D., Renn, O. und Voß, A.: Sanfte Energieversorgung, Jülich, 1984.

Porst, J.: Holz-Zyklus Kenia - Zusammenfassung der Studien des Beijer-Instituts, Berichte für GATE/GTZ, 1984.

Porst, J.: Überwachung eines chinesischen Reisspelzengasgenerators in Mali, Berichte für GATE/GTZ, 1986 und 1987.

Rat von Sachverständigen für Umweltfragen: Energie und Umwelt, Sondergutachten, Stuttgart, 1981.

Ripke, M. und Schmit, G.: Erschließung und Nutzung alternativer Energiequellen in Entwicklungsländern, Cologne, 1982.

Sorensen, B.: Renewable Energy, London, 1979.

UNESCO: Programme on Man and the Biosphere; Ecological effects of energy utilization in urban and industrial systems, Bad Nauheim, 1973.

Umweltbundesamt (Federal Environmental Agency (Ed.)): Lärmbekämpfung 1988, Berlin, 1989.

VDI - Richtlinien - Maximale Immissions-Werte.

Weih, H.; Engelhorn, H.: Wärme und Strom aus Sonnenenergie, Altlußheim, 1990.

WHO (World Health Organization): Environmental Health Criteria, Geneva.