# Guideline for Estimation of Renewable Energy Potentials, Barriers and Effects

April 1996, 2nd ed. March 1997, 3rd ed. December 2006

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**INFORSE - Europe**

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## Introduction
This is an overview on how to asses potentials of renewable energy, and how to make overview calculations of economical, employment and other effects of introducing renewable energy.
It is meant to be used as a tool to make an overview of available resources, which is necessary for any plan to introduce renewable energy locally, regionally or nationally.

Often a distinction is made among physical, technical/environmental and economical potentials. With this distinction, this publication is primarily aimed at finding the technical/environmental potential of the different sources.

This publication is made for overview evaluations. It can NOT be used to calculate available resources for actual designs of renewable energy plants.
It is not a textbook for renewable energy. It can be used in connection with the training material for INFORSE's Distance Internet Education on Renewable Energy Technologies (DIERET), which gives descriptions of the different renewable energy technologies.
The book is made in an European context, and does not include renewable energy for developing countries, or for more remote applications, where stand-alone systems are needed. It is based on experience and projections from Denmark, Germany, Austria and a number of other countries.
While geothermal energy can be an important heat-source in some Central and Eastern European Countries (CEEC), no chapter is included on geothermal energy. The authors find that in most European countries, existing surveys of geothermal energy are more reliable sources of information than simple estimates that could be made on the basis of a guideline like this. See example from Slovakia, page S11.

The book contains overviews of the direct employment of some of the proposals. In direct employment is included the jobs in the manufacturing, installation, operating and maintenance, as well as jobs in suppliers of goods and services.
The wider societal employment effects of the activities are not dealt with. These effects are generally positive in situations where societal costs are reduced, and where imports are reduced. These figures are country-specific and cannot be generalized.

This is one of the results of the project "Partnership for Assessment and Support of Renewable Energy Solutions", organized by OVE, FAE, Polish Ecological Club, Forum for Energy and Development - Denmark, and INforSE - Europe, the European part of the worldwide "International Network For Sustainable Energy".

**Acknowledgments**
The authors are thankful to the following organizations for their financial contributions that made this work possible:
Phare Partnership and Institution Building Program, European Commission DG 1, European Union; Forum for Energy & Development, Copenhagen, Denmark;
Gaia Trust, Skyum, Denmark; Plum's Ecological Fund, Copenhagen, Denmark
Planenergi, Skørping, Denmark

We are also thankful for the valuable contributions from a number of INforSE - Europe organizations.

Potentials for Renewable Energy, Overview of Assessment

| Source | Methods for evaluation | Comments |
|---|---|---|
| Biomass | | |
| Forest | Unused forest fuel:<br>total growth % total removals<br>Existing fuelwood production<br><br>wood industry residues %<br>residues for non-energy use | of commercial forests only |
| Agriculture combustibles | Cereal straw:<br>I: 25% of grain production<br>II:straw production of different grain % use<br>Residues from agro-industry % use<br>Pruning of wine, olive, fruit trees % use<br>Existing use for energy | include annual variations<br><br><br>mainly olives |
| Biogas | Easily collectable manure from pigs, cows, fowls<br>digestible industrial waste<br><br>% 20% auto-consumption | |
| Energy crops | Crops for solid fuel<br><br>Crops for liquid fuel<br><br>%energy consumption in agro-inputs, agriculture etc. | E.g. coppice |
| Non-biological sources: wind, hydro, solar, geothermal | | |
| Wind | I: Use chart of mean wind speed, find areas with wind > 4m/s in 10 m height<br>II:Wind atlas | |
| Hydropower | Use hydrologic evaluation | |
| Solar heating | Houses outside cogeneration / solar district heating: 60-80% of energy for hot water / 20-40% of total heat consumption<br>Industrial hot water < 100$^{o}$C:<br>I: Estimate 30% coverage<br>II:Detailed analyses<br>District heating:<br>without storage: 5% coverage<br>small storage: 20% coverage<br>seasonal storage: 80% coverage | |
| Photovoltaic | Large potentials, expensive | Good off-grid |
| Geothermal | Use existing surveys | |

% is used as minus and percent respectively in this table

# Biomass

## Unused Forest Energy Potential & Fuelwood

Most commercial forests in Europe have an unused energy potential, which can be used without endangering their role in the natural eco-systems. Beside this, most forests already have a production of firewood. Mountain forests and other less commercial forests can in certain cases also deliver wood for energy, but only after due environmental consideration.

The available forest residues are generally branches with diameters smaller than 7 cm. Generally, leaves and roots should be left in the forest to preserve a healthy forest environment. They are also more difficult to use for energy than branches.

It is not enough to use more firewood, the efficiency needs to be increased as well: Traditional ovens and furnaces have in many cases efficiencies as low as 30%, compared with about 80% for efficient furnaces. Increased efficiency can thus more than double the energy outcome of wood burning, without using more wood. For larger installations, flue-gas condensation can raise efficiency further. For larger applications, wood furnaces can be replaced with wood gasifiers + gas motors or steam boilers + turbines, for cogeneration of electricity and heat.

**Energy content**
The energy content in totally dry wood is apr. 5.2 kWh/kg. In normally dry firewood (20% humidity) the energy content is apr. 4.2 kWh/kg (lower heating value). In most statistics, wood is measured in cubic meter solid wood (with or without bark)(Halm&Flis67). The density of dry wood varies from 800 kg/$m^3$ for hard leafy wood (e.g. beech) to 600 kg/$m^3$ for coniferous (e.g. pine). This gives energy contents of respectively 3400 and 2500 kWh/$m^3$ for beech and pine (lower heating value, 20% humidity).
For furnaces with flue-gas condensers, the energy output can be 80-90% of the higher heating value, which is respectively apr. 4% and 10% above lower heating values for wood with 20% and 40% humidity.

**Resource estimation**
The available amount of wood can be estimated from forest statistics as the difference between annual growth (in $m^3$, including bark) and the annual wood extraction for timber and other non-energy purposes. Bark can be estimated to 20% of wood exclusive bark. Often the statistics provide only commercial extraction, to which should be added an estimate of non-commercial use. The non-commercial use is often in the form of firewood-gathering by local inhabitants, and could thus be included in the energy potential. In reality the resource might be lower than this estimate due to problems of extracting all branches and/or due to the need of leaving some branches in the forest for ecological reasons. These two factors can reduce the resource with as much as 50% even in commercial forests (Bornholm).

If forest statistics are incomplete or unreliable, simplified estimates can be made:
- if only figures for commercial use is available, the potential for wood residues can be estimated as a fraction of the commercial use. Danish experience is that wood for wood-chips (branches smaller 7 cm in diameter) is equivalent to 25% of the timber production including bark or 31% of the timber exclusive bark (OVE-Ekowatt).

- if only forest area is known, a first estimate can be made based on area of commercial forest. An estimate from Germany (BUND) gives an annual growth of forests of 10-15 tonnes/ha with an energy content of 150 - 225 GJ/ha (42 - 63 MWh/ha). If 3/4 of this is used for timber, the available residues has an energy content of 40-60 GJ/ha (11 - 16 MWh/ha). An estimation of residues from forests on the Danish island Bornholm gives practical usable residues smaller than 7 cm in diameter of 1.7 tons/ha, equivalent to 18 GJ/ha (5 MWh/ha) with 40% humidity or 25 GJ/ha (7 MWh/ha) with 20% humidity. These estimates do not take into account the important factors of climate and soil for the actual wood production.

**Barriers**

Use of firewood for heating does not in general pose barriers. The efficient and clean use of firewood, however, requires efficient and clean-burning ovens and basic knowledge of the users. Clean-burning and efficient ovens are available with environmental labels, such as the Nordic Swan label.

Using wood-chips requires equipment for producing the wood- chips, storaging, and feeding into an appropriate boiler. The production-chain should be set up as locally as practically possible for best use of wood-chips for heating. Wood-chips are most suitable in larger boilers, above 100 kW. Often wood-chips have high humidity (40 - 60%), and boilers with flue-gas condensation should be preferred. Many boilers cannot use the wet wood-chips (50-60% humidity) and chips for such boilers must be made from dryer wood, e.g. wood that is dried in the forest.

## Effects on economy, environment and employment

**Economy**

Use of firewood and wood-chips are based on a local resource, requires minimal transport/import and is therefore quite inexpensive in comparison to fossil fuels.
Price estimates, excluding transport & profits (of leafy trees, solid density 760 kg/m$^3$, loose density 270 kg/m$^3$):

- Denmark: 120 DKK/m$^3$(loose, density 270 kg/m$^3$) equal to 0.15 DKK/kWh (0.020 €/kWh)
- Danish example with Czech wages: 220 Csk/m$^3$(loose) equal to 0.28 CsK/kWh (0.010 €/kWh)

Of the Danish price 2/3 is wages, while the rest is fuel and machine costs. Of the Czech price 1/3 is wages (wages are ¼ of Danish wages.

**Environment**

Use of wood replacing fossil fuels reduces net $CO_2$ emissions, because the forest absorbs the same quantity of $CO_2$, which is released in the later combustion of the wood. The energy to process the wood is in the order of a few percent of its heating value.
Wood combustion emits very little sulphur ($SO_2$) compared with coal and oil. $NO_x$ emissions depend on the combustion process and often the lower combustion temperature leads to lower emissions than for coal and oil combustion. Emissions of particulate and unburned hydrocarbons are totally dependent on the combustion processes, and can be a problem in small and badly designed furnaces. Ashes from the combustion can often be used as fertilizer, if the content of heavy metals is not too high (because of the concentration of minerals in the ash. Sometimes cadmium is a problem).
It is important that the extraction of wood is done in a sustainable manner, with adequate re-

planting etc.

**Employment**
According to French experience (Bois - Energie), utilizing of excess energy from forests requires 450 jobs/TWh with the degree of mechanization that is normal for Western Europe.

**Hand-rules and country estimates**
Each ha of forest on good soil in Central Europe grows 10 tons/ha of wood. If 25% of this is available as waste-wood for energy, the output for energy is 2.5 tons or 11 MWh (20% humidity).

Unused forest potential + fuelwood production

| Country | Estimate from "Biofuels"* | EU R.E.Study estimate** |
|---|---|---|
| Austria | 4.4 + 14 TWh | |
| Byelorussia | 24 + ? TWh | |
| Bulgaria | 18 + 3.6 TWh | 3.8 TWh |
| Czech Republic | 28 + 1.7 TWh | 6.8 TWh*** |
| Denmark | 4.7 + 1.1 TWh | 3.2 TWh |
| Estonia | 17 + 2.5 TWh | |
| Hungary | 10 + 6.9 TWh | 4.5 TWh |
| Latvia | 21 TWh**** | |
| Lithuania | 19 + 3.3 TWh | |
| Poland | 149 + 6.9 TWh | 16 TWh |
| Rumania | 93 + 3.6 TWh | 9.5 TWh |
| Russia, Europ.part | 265 + 109 TWh | |
| Slovakia | 12 + ? TWh | *** |
| Ukraine | 21 + ? TWh | |
| rem. Yugoslavia | 9.7 + 4.7 TWh | |

* First figure is unused forest potential, second figure is fuelwood production
** Sum of unused and used forest potential, forecast for 2010
*** Figure for Czech and Slovak Republic together given under Czech Republic
**** Figure for total forest growth including timber production

## Residues from wood industry

In saw-mills, pulp mills and all wood processing industries, residues are made that can be

used for energy purposes. From saw-mills is mainly bark and saw-dust. From pulp-mills (cellulose and paper production) is black and sulphite liquors as well as wood and bark residues. From sawmills comes edgings, chips, sawdust, bark and other residues. Some of these residues are used for pulping, and particle-and fibreboard. Analysis of 7 countries shows that 30-70% of wood industry residues are used for these non-energy purposes (Biofuel).
The residues in forms of larger pieces can be made into wood- chips for wood-chip boilers, while sawdust can be burned in special furnaces or compressed into wood pellets of brickets, that can be used in smaller furnaces and ovens.
Often wood industry uses their wood residues to meet own energy demands for heating, steam and eventually electricity.

**Energy content**
The energy content for wood residues are about 4.2 kWh/kg (lower heating value, 20% humidity), equivalent to 3400 and 2500 kWh/m3 for beech and pine respectively. See also previous chapter.

**Resource Estimation**
Evaluation of wood residues can be based on trade-statistics of non-energy wood and wood-products compared with total extraction from forests. The difference is available for energy purposes, and is probably to some extent already used as such in wood industries.
As a simple estimate can be used that residues in general are 25-35% of total forest removals (e.g. Poland 29%, Canada 29%, Finland 33%, Sweden 36%, USA 37% from Biofuels). If a large part of forest removals are exported without processing, the figure will be lower.

**Barriers**
This resource has in general the fewest barriers of all renewable energies. An efficient utilization requires, however, investments in new boilers, or at least in a pre-combustion furnace, that can be attached to an existing (good) boiler.

**Effect on economy, environment and employment**

When the residues from industry are treated as waste without commercial value, the economy of using them for energy is almost always cost-effective, and has a better economy than wood residues from forests. Dry saw-dust and similar that can be used for wood pellets has an increasing market-value because of the market for wood pellets.

Environmental effects are equal to wood residues from forests, as long as combustion of chemically treated and painted wood residues is avoided. Such wood-residues should be treated as municipal waste or chemical waste depending on the treatment.

The direct employment of using industrial wood waste is low because the waste has to be handled anyway. Indirectly it gives considerable employment because it turns unused materials into a valuable product (energy). Production of wood-pellets from wood waste increases the value of the wood and increases employment.

**Hand Rules and country estimations**
Regarding hand-rules, see resource estimation above.

Estimate of wood industry residues minus residues use for non-energy purposes:

| Country | Estimate from Biofuels |
|---|---|
| Austria | 8 TWh |
| former CSFR | 4 TWh |
| Denmark | 1.7 TWh* |
| Finland | 27 TWh |
| Germany | 8 TWh |
| Lithuania | 1.4 TWh |
| Poland | 12 TWh |
| Rumania | 2.2 TWh |
| Russia, Euro.part | 37 TWh |
| Sweden | 44 TWh |

* Estimate from VEiDK.

## Combustible waste from agriculture

Straw, prunings of fruit trees and wine and olive oil residues are all residues from agriculture that can be used for energy purposes. In Northern and Central Europe, straw is by far the most important.
In Denmark and Austria large amounts of straw are used for heating stations, mainly for smaller district heating systems and for large farms; in recent years also for power production in small and large CHP plants. Smaller systems for small farms and individual houses have often problems with achieving a satisfying, clean combustion.

Straw harvest is depending on weather conditions and vary considerably from year to year. The straw surplus has also large variations from year to year. If a large part of the surplus is used, an alternative fuel should be considered for years with little surplus straw. Such an alternative fuel could be wood-chips forest residues, that can be used alternatively with straw in many boilers. The forest residues can stay several years in the forests before usage.

Straw surplus can be ploughed into the field for enriching the humus layer of the field. When this is needed for a sustainable agriculture, the surplus straw for energy will be lower.

**Energy Content**

The energy content of straw is 4.9 kWh/kg of dry matter (high heating value). With a typical of 15% humidity the lower heating value is 4.1 kWh/kg (Halm&Flis67).
The energy in 1 $m^3$ of densely compressed straw bales is 500 kWh (density 120 kg/$m^3$).
The average efficiency for 22 straw-fired heating stations in operation in Denmark is 80-85%, not including flue-gas condensation (Halm&Flis13).

**Resource Estimation**
Estimations of straw production can be obtained from agricultural statistics. This value should be reduced with agricultural consumption of straw for animal fodder and bedding. The agricultural consumption is very dependent on the type of stables used. In Denmark the average available surplus for energy is estimated to 59% of which 1/5 is already used, mainly for heating (Straw). In Eastern Bohemia, this surplus is estimated to about 35% (OVE-EkoWatt). As a general, conservative estimate for Europe 25% of the straw production can be used for energy (Biofuels). The straw production varies +/- 30% from average years to years.

If straw production is not available from statistics, relatively good estimates can be made from statistics of grain production. As a rough estimate the amount in tons of straw can be equalled to the amount of grain in tons (Biofuels). In the Czech Republic the average ratio between straw and grain is found to (Statistical data from VUZT, Research Institute of Agriculture in Prague, 1993):

| | |
|---|---|
| wheat | 1.3 tons straw/tons grain |
| barley | 0.8 tons straw/tons grain |
| rye | 1.4 tons straw/tons grain |
| oat | 1.1 tons straw/tons grain |

A rough estimate can be made based on agricultural area and a straw harvest of 4-7 tons/ha depending on soil, type of grain and weather.

**Barriers**
Limited experience and funds for the necessary investments are often the largest barriers to use straw for energy. Other barriers can be:
- the need to develop a market for straw with attractive prices for users as well as suppliers,
- pesticides can in certain situations give unwanted chlorine compounds in the straw. This can be reduced by leaving the straw for a period at the field, so called wilting.
- use of straw in inadequate and polluting boilers can give straw a bad reputation.

**Effect on economy, environment and employment**

**Economy**
In Denmark, straw-prices varied in 2005 from 0.09 DKK/kWh (1.2 €-cent) to 0.12 DKK/kWh (1.6 €- cent) for baled straw delivered at a straw-firing station (DFF-2005). In Czech Republic the prices for straw collected at the farm has been quoted at 0.043 Csk/kWh (0.15 €-cent) for loose straw and 0.054 Csk/kWh (0.19 €-cent) for baled straw (OVE-Ekowatt).

Costs, based on straw-fired district heating installations in Denmark are per kWh heat produced and delivered to heat network:

| | Danish average |
|---|---|
| Fuel | 1.6 €-cent |
| Electricity* | 0.1 €-cent |
| O&M, administr. | 1.3 €-cent |
| Capital costs | 1.5 €-cent |
| Total | 4.5 €-cent |

* Electricity consumption is in average 2.3% of heat produced

The environmental impact of using agricultural residues are, as for wood, reduced $CO_2$-emission, reduced sulphur emissions, compared with coal and oil. Emissions of particulate,

$NO_x$ and volatile organic compounds (VOC) depend on furnaces and flue-gas treatment. Chlorine components in straw gives emission of HCl as mentioned above. Danish experience from 13 straw-fires heating stations shows the following emissions (all plants have particulate filters) (Halm&Flis61):

| Emission type | Average Emission per kWh straw | Variation of emissions per kWh straw |
|---|---|---|
| Particulate | 0.14 g | 0.01 - 0.3 g |
| CO | 2.2 g | 0.4 - 4 g |
| $NO_x$ | 0.32 g | 0.14 - 0.5 g |
| $SO_2$ | 0.47 g | 0.4 - 0.6 g |
| HCl | 0.14 g | 0.05 - 0.3 g |
| PAH* | 0.6 g | 0.4 - 1 g |
| Dioxin(PFDD + PCDF)** | | 1 - 10 ng |

* PAH = Polyaromatic Hydro-Carbons. This is the carcinogenic part of VOCs.
** Dioxin figures are based on only two measurements, figures in nanogram = $10^{-9}$ g.

**Employment**
The direct employment of harvesting straw in a fully mechanized agriculture in Denmark is estimated to 350 jobs/TWh (from Miljø). This is for technologies with large straw-bales (500 kg each). For a system based on smaller bales (10-20 kg), the employment is larger.

**Country Estimates**
Estimate of agricultural residues, unused + used for fuel.

| Country | Estimate from Biofuels | EU R.E. Study |
|---|---|---|
| Austria | 5 TWh | |
| Bulgaria | 9 TWh | 0.8 TWh |
| former CSFR | 13 TWh | 1.7 TWh |
| Denmark | 16 TWh** | 4 TWh |
| France | 71 TWh | ca. 10 TWh |
| Germany | 42 TWh | 17 TWh |
| Hungary | 16 TWh | 0.5 TWh |
| Poland | 29 TWh | 6 TWh |
| Rumania | 20 TWh | 2.5 TWh |
| Russia, Euro.part | 58 TWh | |
| Slovakia | 1.4 TWh | |

* Data from VEiDK

## Energy Crops

It is estimated that 20-40 million hectares of land in the EU will be surplus to conventional agricultural requirement. The same situation (agricultural overproduction and setting the land aside) can be expected in Central Europe as well. This set aside land can be used for different purposes, one of them is energy crop production.

Promising crops which can be planted for energy purposes in Europe are short rotation trees (coppice of various willows and poplars), Miscanthus and Sweet Sorghum. These crops can be utilized by direct combustion for heat and electricity production. Other promising energy crops are plants for liquid fuels as rape seeds for bio-oil.

**Energy Contents and Yields**
The following table gives an overview of the expected yields and energy contents for three of the promising plants for solid fuel production.

| | Yields (tonnes/ha/year) | Energy content (GJ/dry tonne) | Energy Yields (GJ/ha/year) |
|---|---|---|---|
| Salix (Willow)* | 15 | 16 | 240 |
| Miscanthus (Elephant grass) | 20 | 17 | 340 |
| Sweet Sorghum | 25 | 18 | 450 |

*Increment of Salix is 2-3 meters in one year (2-3 cm per day in the summer), harvest every third year.

Another promising plant is hemp, which has yields up to 24 tonnes/hectare in approximately 4 month. Hemp plantation is illegal in many countries, even though some variants has very little content of cannabis.

**Resource Estimation**
The energy potentials can be estimated from the area of land which is set aside in the country/region and can be used for energy plantation and the expected outcome of the above crops under the actual climate and soil conditions. In most countries, national estimates exists of the different yields of the plants. Using excess farm land and ecologically degraded land should be the priority.

Important feature in estimation of potential is input : output ratio. If the bagasse of Sweet Sorghum (2/3 of its energy content) and the sugar (1/3 of its energy content) are utilised for energy purposes the input : output (I/O) energy ratio will reach 1:5 . This means that five times more energy is recovered from the crop (on fuel basis) in comparison with the energy utilised for the seeding, fertilisers and pesticides treatment, harvesting, transport and conversion into useable fuels. Usually the input : output ratio is larger than 1:5 for trees and smaller for plants for liquid biofuels.

**Barriers**
Short rotation crops may require as much fertilization as traditional crops and degraded land must be regenerated before cultivation using fertilization. For tree crops these drawbacks may

be offset by the fact that they retain an active root system throughout the year. Wood ash would be an effective fertilizer for biofuels plantation, reducing the problems caused by the leaching of fertilizers into ground water.

**Effect on Economy, Environment and Employment**

**Economy, Costs**
Production costs for Sweet Sorghum are about 50 € per dry tonne.
Production cost of Salix are about 70 € (500 DKK) / tonne of dry matter in Denmark (Hvidsted)

Electricity generation cost for biomass (Sweet sorghum ) fuelled system

| **Facility** | €/kWh |
|---|---|
| small 1992 | 0,16 |
| **large 1992** | 0,08 |
| **small improved 2000** | 0,07 |
| **large improved 2000** | 0,05 |

**Environment**
An important feature for Salix is that it can be used for water purification - it is possible to grow Salix in purification systems and in the same time harvest the Salix for energy (10-20 tonnes of sludge can be used on each hectare every year). Other benefits of biomass for energy plantation includes forest fire control, improved erosion control, dust absorption, and used as replacement for fossil fuels: no sulphur emission and lower $NO_x$ emissions.

**Employment**
For Sweet Sorghum production cost 50% is manpower cost. Production of about **500 tonnes of dry biomass** per year justifies the creation of **one new job**. Other new jobs could be created in related industries such as composting, pulp for paper, service organisation etc.

**Hand Rule**
Sweet Sorghum output for trials in different locations of Central and Southern Europe: Annually 90 tonnes of fresh material = 25 tonnes of dry matter per hectare = 450 GJ or 11 tonnes of oil equivalent can be produced. 1/3 as ethanol from sugars and 2/3 of fuel from bagasse. This corresponds to the absorption of 30-45 tonnes of $CO_2$ per hectare and per year. Average yearly electricity consumption of a West European person can be met by growing poplar on 0.25 hectare.

Sources for energy crops section: (SweetSorgh), (Hvidsted), and (Miscanthus).

## Biogas

The largest potential for biogas is in manure from agriculture. Other potential raw-materials for biogas are:

- sludge from mechanical and biological waste-water treatment (sludge from chemical waste-water treatment has often low biogas potential)
- organic household waste
- organic, bio-degradable waste from industries, in particular slaughter-houses and food-processing industries

Care should be taken not to include waste with heavy metals or harmful chemical substances when the resulting sludge is to be used as fertilizer. These kinds of polluted sludge can be used in biogas plants, where the resulting sludge is treated as waste and e.g. incinerated.

Another biogas source is landfills with large amounts of organic waste, where the gas can be extracted directly from drillings in the landfill, to collect landfill gas. Such collection will reduce uncontrolled methane emission from landfills.

**Energy Content**

The biogas-production will normally be in the range of 0.3 - 0.45 $m^3$ of biogas (60% methane) per kg of solid (total solid, TS) for a well functioning process with a typical retention time of 20-30 days at 32$^{o}$C. The lower heating value of this gas is about 6.6 kWh/$m^3$. Often is given the production per kg of volatile solid (VS), which for manure without straw, sand or others is about 80% of total solids (TS).

A biogas plant have a self-consumption of energy to keep the manure warm. This is typically 20% of the energy production for a well designed biogas plant. If the gas is used for co-generation, the available electricity will be 30-40% of the energy in the gas, the heat will be 40-50% and the remaining 20% will be self-consumption.

**Resource Estimation**

For manure, the available data is often the numbers of livestock. From this can be made an estimation of available manure. While the amount of manure produced from animals depends on amount and type of fodder, some average figures are made for most countries.

The following table shows the figures for Denmark and Czech Republic:

| Kind of animal | Manure-type | Amount (kg/day) | Solid | | Biogas | | Energy |
|---|---|---|---|---|---|---|---|
| | | | % | amount (kg/day) | per.kg S. ($m^3$/kg) | per animal ($m^3$/day)** | per animal (kWh/yr) |
| Cow, CZ | slurry | 60 | 7.5 | 4.5 | - | 1.7 | 3,500 |
| Cow, DK | slurry | 51 | 10.6 | 5.4 | 0.29 | 1.6 | 3,400 |
| | | | 23 | | | | |
| Cow, CZ | dry | 38 | 18 | 8.7 | - | 1.2 | 2,500 |
| Cow, DK | dry | 32 | | 5.6 | - | 1.6 | 3,400 |
| | | | 5.7 | | | | |
| Sow, CZ | slurry | 18 | 8.0 | 1.0 | - | 0.3 | 630 |
| Sow, DK | slurry | 16.7 | | 1.3 | 0.23* | 0.46 | 970 |
| | | | 24 | | | | |
| Sow, CZ | dry | 20 | 30 | 4.8 | - | 0.3 | 630 |
| Sow, DK | dry | 9.9 | | 2.9 | - | 0.46 | 970 |
| | | | 11.8 | | | | |
| Hen, CZ | (dry) | 0.2 | 71 | 0.24 | - | 0.016 | 34 |
| Hen, DK | dry | 0.066 | | 0.047 | 0.23* | 0.017 | 36 |

Comparison between Danish and Czech estimate of daily manure and potential biogas-production from the main domestic animals. Yearly energy output is for biogas plant with 20% average self-consumption and 360 working days. When animals are not in stables around the year, the figure will be smaller. The figures are for milking cows and for sows with breeding pigs under 5 kg.
*figure for methane
**biogas with 65% methane

To make an estimation of the yearly production, it should be evaluated how many days per year the animals are in stables. For large poultry farms and pig-farms it is often the whole year, while cows are in stables from a few months a year to the whole year.

To estimate amount of manure from calfs, pigs and chicken, the following estimates can be used (from OVE-Ekowatt):
-calfs 1-6 month: 25% of milking cows
-other cattle ( calfs > 6 months, cattle for meet, pregnant cows): 60% of milking cows
-small pigs, 5-15 kg: 28% of sows with pigs
-fattening pigs > 15 kg: 52% of sows with pigs
-fattening chicken: 75% of hens

**Barriers**
A number of barriers hold back a large scale development of biogas plants in CEEC:
- commercial technology for agriculture (the largest resource base) is not available and have to be developed from existing prototypes or imported.
- it is difficult to make biogas plants cost-effective with sale of energy as the only income. The most likely applications are when other effects of the sludge-treatment has a value. This can e.g. be better hygiene, easier handling, reduced smell, and treatment of industrial waste.
- little knowledge on biogas technology among planners and decision-makers.

**Effect on economy, environment and employment**

**Economy**
The economy of a biogas plant consists of large investments costs, some operation and maintenance costs, mostly free raw materials, and income from sale of biogas or electricity and heat. Sometimes can be added other values e.g. for improved value of sludge as a fertilizer.
In an example from Czech Republic the price for a Czech plant is estimated to about 55,000 € for a plant for treatment of manure from 100 cows. This plant will produce about 220 MWh/year + energy for its own heating. This gives an investment of 0.24€ per kWh/year. New Danish biogas plants have similar investment figures. It is estimated that a joint-venture of Czech and Danish technology could reduce prices by about 40% (to about 0.15 € per kWh/year); but this has not been shown in practice (OVE-Ekowatt).
Operating and maintenance (O&M) will normally per year be 10-20% (Forsyningskataloget) of investment costs, but it vary much with organization, wages, type of plant and eventual transport of sludge. If O&M is 10% of investment costs, simple pay-back requirement is 10 years and no price can be set to increased value of the sludge, the resulting energy price will be 0.03 - 0.045 €/kWh (based on the above examples from Czech Republic).

**The environmental effects of biogas plants are:**
- production of energy that can replace fossil fuels, reducing CO2 emissions
- reduce smell and hygiene problems of sludge and manure
- treatment of certain kinds of organic waste that would otherwise pose an environmental problem
- reduce potential methane emissions from uncontrolled anaerobic degradation of the sludge.
- easier handling of sludge, which can increase the fraction used as fertilizer and facilitate a more accurate use as fertilizer

**Employment**
The direct employment of biogas plants are for Denmark estimated to 560 jobs/TWh, of which 420 jobs/TWh are operating and maintenance, while 140 job/TWh are construction (2000 man-years to construct plants producing 1 TWh and with lifetime of 14 years). This estimate will be valid for mechanized systems with some degree of centralization: some of the manure is transported to the biogas plant from nearby farms.

**Country Estimates**
Only few estimates are made on potentials for biogas production in CEEC countries. Below are figures from the European Renewable Energy Study, which only estimate to use a smaller fraction of the potential. Compare with Danish estimate of full potential.

| Country | Potential Biogas Production |
|---|---|
| Denmark | 8 TWh* |
| former CSFR | 2.5 TWh** |
| Germany | 8 TWh** |
| Hungary | 0.5 TWh** |

| | |
|---|---|
| Poland | 4 TWh** |

* VEiDK
** The European renewable Energy Study, scenario for 2010.

## Liquid Biofuels

The increasing interest in liquid biofuels have given raise to substantial use of plant derived fuels; mainly:
-vegetable oil from rape-seed, sunflower or tropical oil palms for direct combustion in special engines, for processing into biodiesel. The biodiesel is a replacement for diesel fuels or is mixed with diesel oil in normal diesel engines. Used cooking oil can also be used as fuel and for biodiesel.
-ethanol (alcohol) from fermentation of grain, corn, sugar beets, soy-beans or tropical sugar cane for replacement of petrol in special engines or for blending with petrol in normal engines.
The "first generation" biofuels are relatively simple to produce, and are based on well proven technologies; but only a smaller part of the energy in the harvest becomes available as liquid fuel (often 30-40%), and the energy input:output ratio is relatively low (typically 1:2; see table).
Intensive developments are ongoing to produce liquid biofuels from solid biomass crops and from bio-waste. This will require more processing and more advanced technologies; but the expectations are that it will lead to a higher part of the harvest converted into liquid biofuels, a better energy input:output ratio, and possibilities to use cheaper feed-stock such as straw and bio-waste.
Also biogas is used increasingly in transportation.

**Energy Content**
Bio-diesel and pure plant oils have energy contents of about 34.5 MJ/ltr (lower heating value) = 9,6 kWh/l equal to 10,9 kWh/kg. This is about 4% lower than the energy content of diesel (volumetric comparison).

Ethanol has an energy content of 21.1 MJ/l (lower heating value) = 5.9 kWh/l equal to 7,4 kWh/kg. This is about 2/3 of the energy content of normal petrol. Some studies show that the mileage will not decrease 33% by a change from petrol to ethanol-fuels (e.g. 85% ethanol + 15% petrol), but rather 25-30% because of increase in combustion efficiency.

**Resource Estimation**
The table below shows yields of biofuels for European plants and for two tropical plants.

| Crop | Product | Yield (l/ha) | Yield (kWh/ha) | Energy ratio (out/in)** |
|---|---|---|---|---|
| Rape-seed | Biodiesel* | 1000 | 9,500 | 2.5 |
| Sunflower | Biodiesel* | 1300 | 12,500 | n.a. |
| Oil palm | Biodiesel* | 4500 | 43,000 | 9 |
| Grain | Etanol | 1000-2500 | 6,000-14,000 | 2-4 |
| Corn | Ethanol | 3000 | 18,000 | 1.5 |
| Sugar beet | Ethanol | 5000 | 29,000 | 2 |
| Sugar cane | Ethanol | 6000 | 35,000 | 2-8 |

* Alternatively the oils can be used directly as pure plant oils

** Not including energy content of by-products (straw, press-cake, etc) that can have up to twice the energy content of the fuel, improving the energy ratio substantially. The energy ratio for pure plant oil is up to 30% higher than for biodiesel. All figures are approximates, and varies substantially with conditions and processes.

The yields in the table are for good conditions and normal use of fertiliser and pesticide; yields for organic farming are lower.

Source for the table is DIERET.

**Barriers**
**The main barriers are:**
-taxation; in many countries biofuels are taxed similarly to petrol fuels
-concern of automobile producers for use of alternative fuel, and resistence from oil companies
-limitations of available land that can be used in a sustainable way (in some countries)

**Effect on economy, environment and employment**

**Economy**

| **Cost ranges for liquid biofuels 2006** | EUR per liter of gasoline/diesel equivalent |
|---|---|
| Biodiesel from Rape-seed | 0.32-0.65 |
| Biodiesel from waste oil | 0.20-0.37 |
| Ethanol from grain (EU) | 0.40 - 0.65 |
| Ethanol from sugar cane (Brazil) | 0.20 - 0.30 |
| Ethanol from corn (USA) | 0.30 - 0.50 |
| Gasoline (wholesale) | 0.30 - 0.55 |

Source: DIERET

**Environmental effects of liquid biofuels**
The environmental effects must be divided in effects in agricultural production, effects of production facilities, and effects in use.

The agricultural production is not different from other agricultural production. Conversion of existing agricultural land with annual crops have little effect; but can continue existing problems such a leaching of nutrients. Conversion of natural land will increase environmental effects, and these can be devastating, such as the conversion of biodiversity-rich rain-forest into oil palm plantations in Indonesia and Malaysia.

Production facilities for liquid biofuels have smaller environmental effects than oil refineries; but they can have some effects in the neigbourhood, such as odours. A good environmental impact assessment should be made before new facilities are build.

Environmental effect of liquid biofuels are generally lower than of the fossil fuels that they replace; both in $CO_2$-emissions and in local pollution. In particular fuel-spills are less harmfull than fuel spills of fossil fuels. On the other hand, ethanol have a higher vapour pressure than petrol, which might give higher evaporation if no measures are taken to contain it.

**Employment**

Employment of liquid fuel production is similar to the agricultural production of food or fodder that it replaces (for first generation technologies)

**Country Estimates**

The energy production of pure plant oil depends on the area of agricultural land that is allocated to this purpose; but studies have shown that with current technology and current vehicle-efficiency, liquid biofuels will only cover a small fraction of the transport fuel demand in Europe. A conversion of 7% of Danish agricultural land could yield 7 PJ of rape-seed oil that could replace about 4% of Danish energy consumption for road transport. Similarly, conversion of 167,000 ha of agricultural land to rape-seed in Lithiania (5.3% of agricultural land) could yield 4 PJ, equal to about 8% of national road transport energy demand.(VISION)

# Wind energy

**Energy Content**

The energy content of wind varies with the third order of the wind speed. For larger windturbines, only areas with average wind speed above 4 m/s are of interest (measured 10 m above ground). Smaller windturbines for water pumping or battery charging are also used in areas with less wind.

The wind varies sharply with character of landscape and the height above ground. The variation with height is also depending on the character of the landscape. In the following figure is given 4 typical landscapes without hill-effects and their characteristics. The change in mean wind from 10 m to 40 m gives the change from a typical measuring height to a typical hub-height of a large turbine.

| Type of landscape | Relative energy in the wind * | Change in mean wind from 10 m to 40 m | Illustration of landscape |
|---|---|---|---|
| At sea<br><br>Roughness class 0<br><br>Flat landscape, no larger obstacles.<br><br><br><br>Roughness class 1<br><br>Landscape with few trees and houses, rows of trees more than 1000 m apart.<br><br><br>Roughness class 2 | 100 %<br><br>70 %<br><br>53 % | + 13 %<br><br>+ 24 %<br><br>+ 30 % | |

| | | | |
|---|---|---|---|
| Landscape with rows of trees few hundred meters apart, houses.<br><br>Roughness class 3 | 30% | + 43 % | |

* at 25 m height

In hilly landscapes, the shapes of the hills are also influencing the wind-speed and its variations with the height.

For different mean wind speeds, the energy content of the wind is:

| Average wind speed | | Annual energy production | | Typical site |
|---|---|---|---|---|
| 10 m above ground | 40 m above ground | per m2 at 40 m above ground | for 450 kW turbine (960 m2) | |
| 4 m/s | 5.2 m/s* | 450 kWh* | 430 MWh* | Danish open inland, Czech lower mountains |
| 5 m/s | 6.5 m/s* | 875 kWh* | 840 MWh* | Danish coast, Czech 1000 m mountain |
| 6 m/s | 7.8 m/s* | 1,500 kWh* | 1,400 MWh* | |
| 7 m/s | 7.9 m/s** | 1,600 kWh** | 1,500 MWh** | |
| 8 m/s | 9.1 m/s** | (2,400 kWh**) | (2,300 MWh**) | Czech 1000 m mountain top, North Sea |

*Comparison between wind speed at 10 m height and 40 m height is made for roughness class 2, and is only valid in this situation.
**Comparison between wind speed at 10 m height and 40 m height is made for roughness class 0, and is only valid in this situation.
The estimation of annual energy production is made for a Bonus 450 kW windturbine at an average wind of 6.5 m/s with use of Danish windatlas model, 1991. For other windspeeds, the production is approximated from this with the third order of wind speed ratios. For high windspeed areas (production figures in paranthesis), the estimated production is above the normal range of the turbine, and a special version of the turbine can be necessary.

In most areas of Europe, wind data is available from meteorological stations measuring 10 m above ground. To derive mean wind speed and available wind energy at a given site, it is necessary to consider a number of factors:

- obstacles (landscape roughness) of the site compared with the measurement station. In Danish wind evaluations, the landscape roughness is evaluated in 8 directions, and a weighted average is made according to prevailing winds;
- elevation; the higher the elevation the higher mean wind speed. For Czech Republic it was found that average wind speed increased from 2.5 m/s below 650 m above sea level to 7 m/s at 1500 m above sea level,

- hill effects: sites at or nearby hills and mountains are very dependant of very local conditions,
- distribution of wind-speed: a wind regime with a constant wind-speed has less energy in the wind than a wind regime with same average wind, but with a widespread distribution to high and low winds,
- reliability of data: often wind measurement equipment is not calibrated very often and has a tendency to give reduced readings because of dirt in the bearings.

If reliable data is available for wind speed and direction for at least 6 times a day for at least 3 year, a computer model (the WASP model from Risø Laboratory, Denmark) can give good estimations of wind energy potentials. If this is not the case, on-site wind measurements often can give an estimation of available wind energy at a given site, when data are compared with wind data from a nearby meteorological station.
As a first estimate, simply comparing landscape and elevation of a site with a nearby meteorological station can give an indication of available wind energy. Also wind-shaped vegetation indicates a high-wind area with a dominant wind direction.

**Resource Estimation**

To estimate the resource of a larger area, the available area and wind speed of each part of this area must be known. For a given site 16 windturbines of 500 kW (40 m rotor diameter) can be placed in 1 $km^2$, with 5% reduction of the energy output compared with a single turbine at the same site. To estimate the available area, the area with sufficient wind should be found, and reduced with:
* forested areas
* areas with other important obstacles or badly sited compared with hills and mountains,
* areas closer than 200 m to living areas (to reduce noise level at dwellings below 40 dB, A-weighted) and 75 m to other buildings, roads and rails (for safety, Danish regulation),
* nature protection areas and important bird areas.

National legislation and other land-use interests can give other restrictions of windmill-sites. Windmills are not restricting the use of an area for agriculture, but can reduce the recreational value of a landscape and can sometimes be seen as problematic in relation to historical sites and landscapes of special interest (for various reasons).

**Barriers**
The main barriers to use of windturbines in areas with sufficient wind is:
- lack of grid-connection possibilities with reasonable payment for the produced electricity,
- no grid in the area, larger windturbines are typically connected to a 10 kV grid. This is mainly a problem in remote areas, which often can have good winds.
- lack of financing. Almost all costs of a windturbine are investment costs, a good source of financing therefore very important,
- unknown technology. In many countries there is no experience with reliable, efficient windturbines. Without this experience, investors and entrepreneurs are less likely to go forward with windturbine projects.

**Effect on economy, environment and employment**

**Economy**
The investment of a 600 kW turbine can be estimated to 540,000 € (Bonus). This windturbine produces 1.150 MWh/year at a mean wind speed at 40 m height of 6.2 m/s and 2,300 MWh/year

at a mean wind speed at 40 m height of 9.1 m/s.

With a 10 year simple pay-back requirement* and operating and maintenance of 5000 €, electricity prices for the two wind-speeds will be respectively 0.051 €/kWh and 0.026 €/kWh. These figures are typical for installation of larger series of turbines, not for the first demonstration turbine.

*equivalent to a 20 year lifetime, annuity financing with an interest of 9% p.a.)

**Environment**

The electricity produced from a windturbine replaces electricity produced in more polluting ways, which is the main environmental effect. The energy produced to produce a windturbine is equivalent to 2-4 months of production of the turbine (SEN12).

The local impact of the environment is minimal if the above siting rules are followed. Several studies are made on the effect of bird life. The conclusion is that birds are able to fly safely around windturbines, except a few large species, e.g. the american eagle.

**Employment**

The majority of the employment is in the production and installation of windturbines. Based on Danish experience, the employment is 10 - 11 man-years per installed MW, including manufacturing of the turbine, manufacturing of the components and installation. This is similar to an employment of 300 jobs/TWh (Energy & Employ).

**Country estimates**

Only a few country estimates are made for CEEC. Hereby some figures from The European Renewable Energy Study, with a more optimistic study for Denmark to compare.

| Country | Wind Energy Potential |
|---|---|
| Denmark | 10 TWh (excluding off-shore) |
| former CSFR | 1 TWh |
| Germany | 23 TWh |
| Hungary | 0 TWh |
| Poland | 5.5 TWh |

# Small Hydro Power

Hydro power is a mature technology with many positive features.

* Its flexibility regarding adaptation to quick load variations makes it a favoured component in any integrated power system.
* Plants can last for very long time. Some are more than 70 years old and still in operation. Plants commissioned recently may show even longer life span and thus can serve consumers over several generations without polluting the atmosphere.
* Investment in hydro power have proved to be safe and secure over several decades.
* Despite the long pay-back times for investment (10-15 years), the future value of hydro power plants is very high due to low operation costs.
* In CEE countries (except of former USSR) the highest unused potential for building small hydro power plants can be expected in Bulgaria, Rumania, Poland and Slovakia.

Small hydro power plants are in large majority connected to the electricity grids. Most of them are of the "run-of-river" type, meaning simply that they do not have any sizeable reservoir and produce electricity when the water provided by the river flow is available but generation ceases when the river dries-up and the flow falls below a predetermined amount.

Small hydro schemes have different configurations according to the head. High head schemes are typical of mountain areas, and due to the fact that for the same power they need a lower flow, they are usually cheaper. Low heads schemes are typical of the valleys and do not need feeder canal.

Of the numerous factors which affect the capital cost, site selection and basic lay-out are among the first to be considered. Adequate head and flow are necessary requirements for hydro generation.

TURBINE TECHNOLOGIES

| Turbine type | Flows $m^3/s$ | Heads in meters (best) | Remark |
|---|---|---|---|
| BANKI | 0,05 - 10 | 1 -50 (>4) | easy manufactured |
| PELTON | >0,01 | >30 | |
| FRANCIS | higher flows | >0,8 (10) | for higher power capacities |
| KAPLAN | 0,1-30 | 1-20 | good regulation |

**Resource Estimation**

In run-of-river schemes, the installed capacity and the annual energy production results from the rate of flow and the available head. The result of the hydrologic evaluation should strive to predict what the flows will be during the life of the project. The accuracy of this prediction depends on the availability of flow records and the time and financial resources available. However not all the flow can be used to generate energy. A certain amount must bypass the works between the intake and the restitution of the water to safeguard water life in this river section.

For most European countries, detailed hydrological evaluation are available, giving a good overview of the potential for small hydro-power.

Estimation of power output P of a site can be estimated according to following equation:

$$P = k*h*Q \text{ (kW)}$$

where

***k*** - is coefficient which depend on efficiency of machinery. The average value of ***k*** is 6 (efficiency of 0.6 * mass acceleration, $g = 9.82\ m/s^2$)

h - is net head of water (difference between height of water level at the place from where the water is taken to the height at the place of turbine) multiplied by 0,9 when losses are at 10%, h is in meters (m)

Q - is average water flow. When the water is forced through different path as the original river route - than the value should be multiplied by 0,8. Q is in $m^3/s$

Estimation of annual electricity production E

$$E = P*t \text{ (kWh)}$$

where t is estimated number of operational hours in the year. Mostly it is supposed to be 5.000 hours.

**Barriers**

The high investment costs is the largest barrier in development of small hydro power schemes. The available financing is therefore often crucial for success with realization.
Environmental impacts can also be a barrier for development of small hydro power plants, see below.

## Effect on Economy, Environment and Employment

**Economy**

Despite high investment costs and long pay-back times (7-10 years in Slovakia) small hydro power plants are often cost-effective because of their long life-time (often more than 70 years) and low maintenance costs.
They investment costs include:

* Construction (dam, channel, machine house),
* Parts for electricity generation (turbine, generator, transformer, power lines),
* Other (engineering, ground property, commissioning)

Total cost of new small hydro power plants in Germany - 10-16 DM/W (5-9 €/W) and are divided in most cases 35% (construction) - 50% (electricity parts) - 15% (other).
Costs of 8 kW turbine (Banki type with regulation) in Czech republic is 4000 USD, equivalent to 3,500 € or 0.45 €/W.

**Environment**

Hydro power plants cannot be built without some damage to ecosystems, naturally the largest impact is related to large schemes which are not considered here. Never the less the impact should always be compared to traditional ways of power generation in the country or region. The installation of a hydro power plant inevitably provokes a change in the natural water flow: the water intake is an obstacle for migrating fish and the diminution of flow between intake and restitution can hamper the aquatic life in this section of the stream. Fish-passes adapted to each type of rivers are available. In some cases small hydro power plants can be built on the most polluted rivers where there are no fish. Unfortunately there is a lot of such rivers in CEEC.

**Employment**

According to Slovak experiences, small hydro power development will give 70 jobs/MW in construction sector and 30 jobs/MW in other sectors (e.g. manufacturing of components), during a three year construction phase. This is equivalent to 210 job-years/MW in construction and 90 job-year/MW in other sectors. With the estimation that 1 TWh can be produced by 216 MW installed capacity, it will take the total employment of 65,000 job-years to construct capacity to produce 1 TWh/year. If the variation of the flow of the rivers are large, it might bee needed to construct more capacity to produce 1 TWh, as it can be seen in the following example from Slovakia. This will give higher employment per produced amount of energy, but a less favourable economy.

These figures are based on 100% manufacturing and construction in Slovakia, and as the employment figure is lower in Western Europe, it is likely also to be lower in developments with joint-ventures, combining technologies from East and West.

In general employment figures for small hydro should be used with caution because the necessary work varies considerably from site to site, also when the same technology is applied.

**Hand Rule and Country Estimate**

In a typical small hydro power plant every litre per second ($10^{-3}$ $m^3$) of water falling down from 1 meter height can produce 20 - 30 kWh of electricity per year.

| SMALL HYDRO POWER PLANT POTENTIAL, SELECTED COUNTRIES | ANNUAL PRODUCTION TWh |
|---|---|
| BULGARIA | > 2.5 |
| CZECH REP. | 1.66 |
| HUNGARY | 0,032 |
| RUMANIA | 4 |
| SLOVAKIA | 1,2 |

Sources for this small hydro section: (Impact), (Danube)

# Solar Energy

## Solar heating

This section is mainly covering active solar heating, where the solar energy is transferred to heat in solar collectors and from there transported by a fluid to its final use. Another important use of solar heat is passive solar heating, where buildings are designed to capture the maximum of the solar energy coming through windows and upon walls to be used for space-heating.

**Energy Content**

The yearly incoming solar energy varies from 900-1000 kWh/$m^2$ North of the Baltic Sea to e.g. 1077 kWh/$m^2$ in Hradec Kralove in Bohemia and up to 1600 kWh/$m^2$ in Mediterranean and Black Sea areas on a horizontal surface. On a south sloping surface, the incoming solar energy is about 20% higher.

**Resource Estimation**

The incoming solar energy on most buildings exceed the energy consumption of the building, e.g. a 5 storey apartment house in Hradec Kralove receives 1077 kWh/$m^2$, while each storey consumes about 150 kWh/$m^2$ for heating and 25-50 kWh/$m^2$ for light and cooking, adding up to 875 - 1000 kWh/$m^2$ for the 5 storeys together (all measured per. $m^2$ horizontal surface).
While the incoming solar energy is sufficient over the year, the practical usable resource is limited by the fluctuations of the solar energy and the storage capacity. Reasonable good estimates of usable solar heat can be made as a fraction of the different heat demands.

For house-integrated systems, the limitations are normally that solar heating can only cover 60-80% of the hot water demand and 25 - 50% of space heating. The variations are depending on location and systems used. In Northern Europe the limitations are respectively 70% and 30% for hot water and space heating coverage.

For central solar heating systems for district heating, analyses and experience show that these systems can cover 5% of consumption without storage, 10% with 12 hour storage and about 80% with seasonal storage. These figures are based on district heating systems which have 20% average energy losses and mainly deliver to dwellings. The energy delivered from solar heating systems without storage is by far the cheapest solution (OVE-Ekowatt).

For industries that uses heat below 100°C, solar heating can cover about 30% if they have a steady consumption of heat (VEiDK). For drying processes solar energy can cover up to 100% depending on season, temperature, and limitations to drying period.
Solar heating to swimming pools can cover most of the heat demand for indoor pools and up to 100% for outdoor pools used during summer.

To evaluate the potential for solar heating is, thus, most a question of assessing the demand for low-temperature heat.

**Barriers**

Most applications for solar heating are well developed, and the technical barrier is more lack of local availability of a certain technology than lack of the technology as such. Thus the main barriers, beside economy, are:

- lack of information of available technologies and their optimal design and integration in heating systems.
- lack of local skills for production and installation.

In some occasions lack of access to solar energy can be a barrier. For active solar heating it is almost always possible to find a place for the solar collectors with enough sunshine. For passive solar energy, where the solar energy is typically coming through normal windows, neighbouring buildings or high trees can give a severe reduction of the solar energy gain.

**Effect on economy, environment and employment**

**Economy**

The economy of using solar energy ranges from almost no costs, when simple passive solar energy designs are integrated into building design and land-use planning to very high costs for solar heating systems with seasonal storage. For solar heating systems, some typical prices are for installed systems:

| Application | Collector size | Annual production | Invest./ area | Invest./ annual prod. |
|---|---|---|---|---|
| Single family hot water, Northern | 4-6 m2 | 2,000 kWh | 1000 €/m2 | 2.5 €/kWh |
| Single family hot water, South Eu. | 4 m2 | 2,500 kWh | 250 €/m2 | 0.4 €/kWh |
| Swimming pool, outdoor | 100 m2 | 10,000 kWh | 10 €/m2 | 0.1 €/kWh |
| District heating | 1000 m2 | 440 kWh/m2 | 181 €/m2 | 0.41 €/kWh |

Notes:

The application for single family hot water, Northern is a typical system for hot water as used in Nordic countries and Germany with anti-freeze agent, high insolation, and closed circuit. The single family Southern Europe is a single family system as used in Greece. Prices in Central & Eastern Europe can be considerably lower. Self-built systems are also considerably cheaper.

The annual production is given for Northern European conditions, except for the Southern European single family system, where production is given for Southern European conditions.

The savings are net savings, in most applications in Northern Europe, the solar heat replaces an oil or gas boiler that has a very low efficiency (often 30-50%) during summer. The total savings can then be 2-3 times larger than the net savings.

**Environment**

The heat produced in a solar heater replaces energy produced in more polluting ways, which is the main environmental effect. The energy produced to produce a solar heater is equivalent to 1-4 years of production of the solar heater (VEiDK).

Usually the solar collectors are mounted on top of a roof, in which case there is no local impact of the environment.

**Effects of employment**

The majority of the employment is in the production and installation of solar heaters. Based on Danish experience, the employment is estimated to 17 man-years to produce and install 1,000 m2 of solar heaters for families (Energy & Employ). These 1,000 $m^2$ replaces 800 MWh of primary energy (net energy production 400 MWh). With 30 years lifetime of the solar heaters, the constant employment of producing solar heaters to replace 1 TWh will be 700 persons.

**Country Estimates**
In principle all heat demand can be covered by solar energy with seasonal storage. There is therefore no absolute limit to this resource, only economical limitations. In Denmark it is estimated that without seasonal storage, solar energy can cover 13% of the heat demand, including commercial and industrial use. In more sunny places, this fraction is naturally larger.

## Photovoltaic Electricity

Photovoltaic (PV) cells produce direct current electricity with output varying directly with the level of solar radiation. PV cells are integrated in modules which are the basic elements of PV systems. PV modules can be designed to operate at almost any voltage, up to several hundred Volt, by connecting cells and modules in series. For applications requiring alternating current, inverters must be used.

Today exist various usable types of photovoltaic cells. Mono crystalline cells, poly crystalline, and amorphous cells, all made of silicon. Silicon is made from quarts ($SiO2$), which exists in large quantities in nature. The silicon used must be very pure, and the production process requires considerable energy. The pure silicon is doped (*polluted*), e.g. by boron, and thereafter various substances are steamed on. Parts of the production processes are secret, as a costly development is taking place. The development is heading toward still thinner substrate cells, double function cells, and tandem cells. In the future we will also see granular photovoltaic cells with lower efficiency, but at considerable lower price than today's photovoltaic cells.

PV cell efficiency is calculated as the percentage difference between the irradiated power (Watt) per area unit ($m^2$), and the power supplied as electric energy from the photovoltaic cell. There is a distinction between theoretical efficiency, laboratory efficiency, and practical efficiency. It is important to know the difference between these terms, and it is of course only the practical efficiency which is of interest to users of photovoltaics.

Practical efficiency of mass produced PV cells:

| | |
|---|---|
| single crystalline silicon | 16 - 17% |
| polycrystalline silicon | 14 - 15% |
| amorphous silicon | 8 - 9% |

PV systems are usually divided in:

1. Stand-alone systems that rely on PV power only. Beside the PV modules they include charge controllers and batteries.
2. Hybrid systems that consists of a combination of PV cells and a complementary means of electricity generation such as wind, diesel or gas. Often smaller batteries and chargers/controllers are also used in these systems.
3. Grid connected systems, which work as small power stations feeding power into the grid.

**Tips and Applications**
When designing a photovoltaic installation a number of things must be taken into consideration, if an optimum solution is wanted. At first it must be clarified, how much energy is demanded from the photovoltaic installation. After that the total daily consumption in Ampere hours (Ah) must be estimated. From the total daily and weekly consumption the total energy storage capacity can be calculated. It must be considered how many days without sun, the installation shall be capable of functioning. At the end it can be calculated, how many photovoltaic modules are required to produce sufficient energy. The photovoltaic application can also be combined

with other energy sources. A combination of small wind generators and photovoltaics is an obvious possibility. The energy can be stored in good lead batteries (solar batteries, traction-batteries) or in nickel/cadmium batteries. New energy storage types are under development as sodium/sulphur batteries, and high-efficiency electrolysis of water to hydrogen.

**Resource estimation**

The solar energy which is available during the day varies because of the relative motion of the sun, and depends strongly on the local sky conditions. At noon in clear sky conditions, the solar irradiation can reach 1000 W/$m^2$ while, in very cloudy weather, it may fall to less than 100 W/$m^2$ even at midday. The availability of solar energy varies both with tilt angle and the orientation of surface, decreasing as the surface is moved away from South.

Commercial cells are sold with rated output power (Watt peak power, $W_p$). This corresponds to their maximum output in standard test conditions, when the solar irradiation is near to its maximum at 1000 W/$m^2$, and the cell temperature is 25$^o$C. In practice, PV modules seldom work at these conditions. Rough estimate of the output (P) from PV systems can be made according to the equation:

$$P\ (kWh/day) = P_p\ (kW) * I\ (kWh/m^2\ per\ day) * PR$$

where:

$P_p$ is rated output power in kW, which is equivalent to efficiency * area in $m^2$

I is solar irradiation on the surface, in kWh/$m^2$ per day

PR is Performance Ratio determined by the system.

Daily mean solar irradiation (I) in Europe in kWh/$m^2$ per day (sloping south, tilt angle from horizon 30$^o$):

| MONTH | South | Central | North |
|---|---|---|---|
| January | 2.6 | 1.7 | 0.8 |
| February | 3.9 | 3.2 | 1.5 |
| March | 4.6 | 3.6 | 2.6 |
| April | 5.9 | 4.7 | 3.4 |
| May | 6.3 | 5.3 | 4.2 |
| June | 6.9 | 5.9 | 5.0 |
| July | 7.5 | 6.0 | 4.4 |
| August | 6.6 | 5.3 | 4.0 |
| September | 5.5 | 4.4 | 3.3 |
| October | 4.5 | 3.3 | 2.1 |

| | | | |
|---|---|---|---|
| November | 3.0 | 2.1 | 1.2 |
| December | 2.7 | 1.7 | 0.8 |
| **YEAR** | 5.0 | 3.9 | 2.8 |

Typical Performance Ratios:
0.8 for grid connected systems
0.5 - 0.7 for hybrid systems
0.2 - 0.3 for stand alone systems for all year use

**Typical System Performance**

Stand alone systems have low yields because they operate with an almost constant load throughout the year and their PV modules must be sized to provide enough energy in winter even though they will be oversized during summer.
Typical professional systems in Europe have annual average yields of 200 - 550 $kW_p$.

Hybrid systems have higher performance ratio, because they can be sized to meet the required load in the summer and can be backed up by other systems like wind or diesel in the winter and in bad weather.
Typical annual average yield is 500 - 1250 $kWh/kW_p$ depending on the losses caused by the charge controller and the battery.

Grid connected systems have the highest Performance Ratio because all of the energy which they produce can either be used locally or exported to the grid.
Typical annual yield is 800 - 1400 $kWh/kW_p$.

**Barriers**
Despite a declines in costs, PV cells currently cost about 4 €/$W_p$. Electricity generation costs is currently about 0.5 €/kWh, which is higher than from other renewable energy sources. In the future, the costs of PV are expected to fall with increasing utilization. Despite its high costs, PV electricity can be cheaper than other sources in remote areas without electric grid and where production of electricity by other means like diesel is difficult or environmentally unacceptable (mountain areas).

**Effects on economy, environment and employment**

When the only cost-effective applications of PV systems in Europe are remote areas without electric grid, it will have a positive economical effect only for those areas.

There are no environmental effects of using PV systems. Environmental problems can occur in the production of the cells, and in the production and (improper) disposal of the batteries.

The use of PV is not expected to have any measurable employment effect in Europe for the time being.

**Hand Rule**

In a typical photovoltaic system based on crystalline Silicon with 12% efficiency each $kW_p$ of installed power capacity can produce 1150 kWh of electricity per year for grid connected systems and 300 kWh/year for stand alone systems in Central Europe.

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