Comparison of renewable energy resources in Alpine regions

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Abstract

In recent years, renewable energy sources (RES) received great attention as an alternative to traditional energy sources and as a possible contribution to mitigate climate change effects. Austria aims on increasing the share of renewables in the energy mix and thus took a wide variety of measures. For Alpine regions there are some distinctions regarding applicability and potentials of RES which have been investigated in this paper. It has been found that hydropower, bioenergy and geothermal energy have good potentials whereas photovoltaics and wind energy face some restrictions.

Keywords: Alpine environment, energy potentials, greenhouse gas, renewables

1 Introduction

1.1 Background

In recent years, renewable energy sources (RES) received great attention as an alternative to traditional energy sources and as a possible contribution to mitigate climate change effects (IPCC 2007a). The number of facilities utilising renewables for power generation underwent outstanding growth (figure 1) which may be attributed to a generally increased ecological awareness, permanently rising prices for fossil fuels and a paradigm shift in European environmental policy (e.g. Kyoto protocol, (UNFCCC 1997) with accompanying subsidies and an according legislation.

According to the "EU Directive for Electricity produced from Renewable Energy Sources" (2001/77/EC), a 21% share of renewables in the energy mix for electricity consumption is targeted within the EU with its 25 member states by 2010. For 2003, RES provided 14% (corresponding to 394 TWh) in electricity generation (EC 2005).

RES play a prominent role in Austria's energy supply. Consisting primarily of large hydropower schemes and biomass use (which comprised more than 98% of renewable energy supply in Austria in 2001), the overall share of RES amounts to 21.5% of primary energy supply. Mainly due to policy support and high fossil fuel prices in the 1970s, total renewable energy supply has increased steadily over the past few decades (figure 1). Electricity generation from RES (RES-E) raised from 37 TWh in 1997 (without pumping electricity) to 40.3 TWh (with 87% from hydropower) in 2006 (e-control 2007). Having hence the largest ratio of RES-E among the EU-25 states with 70% (1997), Austria aims on increasing this share to 78.1% in 2010 (as an indicative target) in fulfilment of the mentioned EU Directive.

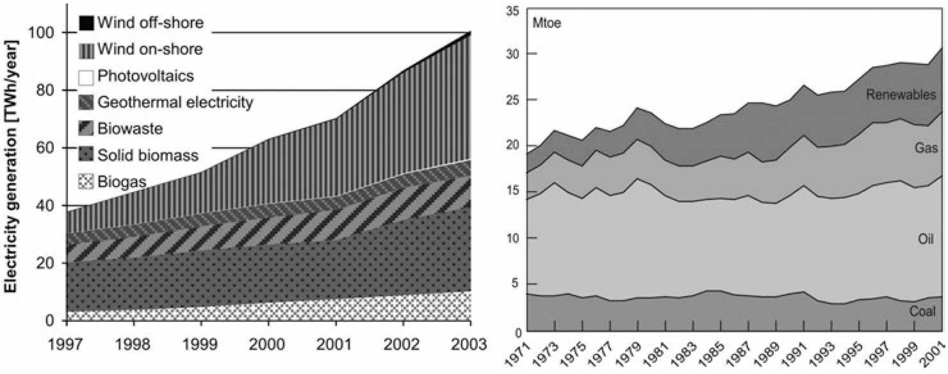

Figure 1: Electricity generation from renewables in EU-25 (left, EC 2005) and total primary energy supply by source in Austria (right, IEA 2004)

However, from a today's viewpoint, it is very unlikely that Austria will succeed in accomplishing this ambitious goal as well as its efforts to meet the Kyoto-obligations. For example, total 2004 greenhouse gas (GHG) emissions were 15.7% above 1990 levels although a target of minus 13% is to be met according to the 2008–2012 Kyoto protocol commitment period (UNFCCC 2006, e-control 2007 and ADTL 2007). Facing these discrepancies and a continued increase in energy demand (annual increase > 2%), the government agreed in 2007 to take intensified measures to extend the share of renewables in the energy mix, being aware that effective emissions reduction is only possible in combination with measures for improved energy efficiency and energy savings (BMLFUW 2007; e-control 2007; ADTL 2007).

As an outcome of countless research work conducted against the background of climate change and affiliated topics, it is very likely that temperature extremes and heavy precipitation events will continue to become more frequent also in Alpine regions (IPCC 2007b), having major consequences for the utilisation of different kinds of RES. However, intensity and frequency of projected extreme events vary depending on the emissions scenario.

As there are partly considerable differences between Alpine environments and lowland regions regarding the technical and economic applicability as well as the ecological sustainability of RES, a differentiating approach appears to be reasonable and essential in order to develop planning and decision criteria at regional level. Within this study, numerous sources have been reviewed with a special focus on potentials and restrictions of exploitation of RES in the Alpine environment. Referring to Austria in wide parts of this study is mainly due to the country's appropriateness to serve as a predestined example for an Alpine region.

Each RES has unique characteristics in terms of level of maturity, ecological and socio-economic appropriateness as well as technological, financial, legal and resource-related requirements for applicability. Employment and future development of different RES technologies of course depend to a large extent on the set-up of national and supranational legislation including governmental and administrative incentives and barriers. This approach has a controversial aspect as differing grants can lead to market distortion. Also, considering GHG savings, a life-cycle approach should be applied including all emissions during manufacturing, operation and decommissioning.

Hydropower, solid biomass for heat and geothermal energy are the most mature RES, and they are largely cost-competitive without special policy support. Concerning Austria's energy supply, the focus historically concentrated primarily in large hydropower plants and biomass use. Less mature, emerging renewables (i.e. wind power, solar technologies and newer forms of bioenergy) which have been entering the markets in recent years, have received governmental support for both technological development and market deployment (IEA 2004).

1.2 Definitions

Primary energies embodied in RES are transformed by energy conversion processes to more convenient energy carriers which form the three sectors of renewable energy: electricity production (RES-E), biofuels as well as heating and cooling. For the present text, according to the definitions made in EC 2005, renewable energy resources comprise the following, non-fossil technologies: hydropower, biomass, biogas, geothermal energy, solar energy (photovoltaic and thermal), wind energy, and wave and tidal power. The latter is not considered in this study due to a poor relevance for Austria and neighbouring Alpine regions.

2 Individual RES technologies and their relevance for Alpine regions

2.1 Hydropower (HP)

2.1.1 General

Hydroelectric power is derived from the potential energy of falling or flowing water driving a water turbine that spins a generator. The energy extracted is proportional to the rate of flow and the difference in elevation between the source and the water's outflow (head). HP generation is either done by: run-of-river plants, impoundment hydropower plants (including damming water in a reservoir), pumped-storage plants or combinations of the above. While run-of-river and small HP plants provide base load electricity due to a poor storage capacity, impoundment and pumped storage hydroelectricity produces electricity to supply high peak demands and is utilised to compensate for grid oscillations.

2.1.2 Energy potential

Traditionally, HP has the lion's share in the Austrian energy mix. In 2005, 58% of the country's electricity production originated from HP plants (compared to 11% in EU-25). With an energy efficiency of around 90%, HP is the most efficient conversion of energy (Verbund 2006). Due to a beneficial topographical position, with ample water resources and large hydraulic heads, renewable energy from water was utilised long before climate protection and global warming became topics of public awareness.

According to (Verbund 2006), Austria has a theoretical HP potential of 150,000 GWh. 56,200 GWh are quantified as economically feasible of which 40,000 GWh (71%) are already exploited until present day. For Tyrol the economically feasible potential amounts to 6000 GWh (ADTL 2007). For the EU-15 states an increase in HP electricity between 1 to 4% and 15 to 25% is projected from the 2001 level until 2020 for large and small-scale HP respectively (Ragwitz et al. 2005).

2.1.3 Aspects in Alpine regions

Generally, it can be stated that HP is more economically attractive than other options (UNDP 2000). However, together with wind energy, HP in Alpine regions represents an energy source characterised by a natural volatility. Other than in lowland regions, most of the energy is produced by impoundment HP producing valuable peak load electricity. Plants access large heads but rather widely branched catchment areas which imply storage facilities. Subsequently, its potential in terms of available water resources is very sensitive to impacts of climate change like precipitation and snow and glacier melt (De Toffol et al. 2007).

Moreover, dams and reservoirs serve for flood control purposes as they increase minimum discharge levels in winter and compensate flood peaks in summer. Drawbacks involve changes in the downstream river environment (e.g. scouring of river beds and loss of riverbanks, fluctuations in river flow) and disruption of surrounding aquatic ecosystems (e.g. hindering fish migration).

2.2 Bioenergy (BE)

2.2.1 General

Biomass which is utilised for heat production, electricity generation and biofuel refinement includes various forms. It comprises solid, liquid and gaseous organic feedstock like solid biomass (e.g. wood chips, purpose-grown energy crops), biogas (e.g. sewage sludge gas, gas from biogas plants fed with substrates of agricultural origin) and liquid biofuels, usually either bioalcohols or bio-oils produced from biomass (e.g. bioethanol, biodiesel, biodimethylether). Biomass also includes the organic component of industrial and municipal waste, but not inorganic waste.

2.2.2 Energy potential

Together with large-scale hydropower, the use of biomass in Austria is among the highest in Europe comprising more than 98% (54.5 + 43.9) of renewable energy supply (primary energy) in Austria in 2001 (IEA 2004). When converted to electricity via digestion and gasification the efficiency (electrical) averages out at 10 to 40% whereas in CHP units for the combustion of biomass efficiencies (overall) of > 80% are reported (UNDP 2000). This can be attributed to a very high appropriateness of solid biomass for thermal energy generation (e-control 2007).

In Austria, 43,646 GWh have been converted from solid biomass to energy in 2004 including 1,112 GWh for electricity production from biomass and biogas (e-control 2007). Based on studies in Ragwitz et al. 2005 and e-control 2007, an annual bioenergy potential of additional 23,352 GWh (comprising 14,456 GWh from energy crops, 6,116 GWh from solid biomass and 2,780 GWh from residual materials) has been determined. Biogas which has been used primarily for electricity production so far is thought to have the potential to substitute 15% of the current natural gas consumption (FGW 2007). According to studies by (Ragwitz et al. 2005) biomass electricity generation are expect to increase by more than a factor of three by 2020. A factor of more than four has been calculated for biogas electricity.

2.2.3 Aspects in Alpine regions

Among other factors, the potential capacity of an (agricultural) biogas plant depends on the available feedstock which in turn depends on the available acreage and livestock. As in Alpine regions farm structures are rather small-sized, most plants have to be designed for small-scale operation (figure 2) which has often been considered economically unfavourable due to costly individual planning and dimensioning. These shortcomings are for example challenged by development of an innovative plant (BIO4GAS) with standardised design and construction elements applicable to a wide range of livestock (Wett et al. 2006).

For both, biomass and biogas saturation effects have been observed due to shortened feedstock availability and subsequent increase of prices. For example, for solid biomass the situation tightens in mountainous regions compared to plain woodland: the higher the demand the higher the costs as more and more difficult accessible mountain forests have to be harvested.

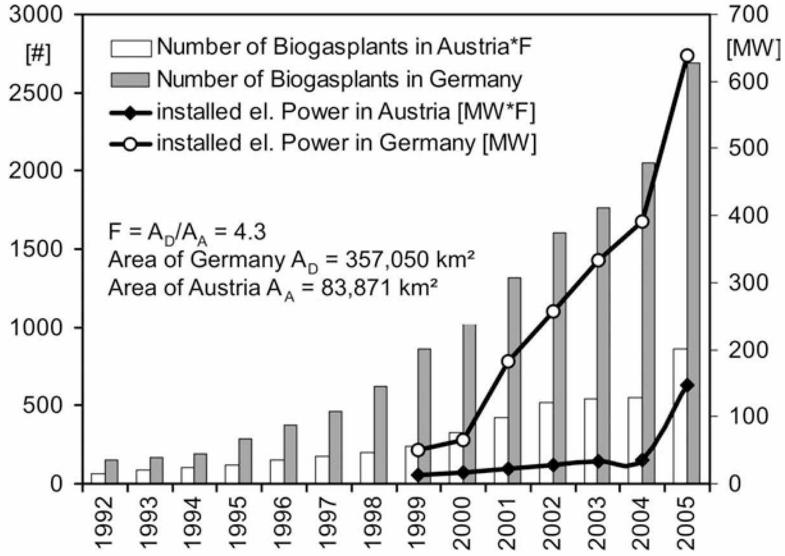

Figure 2: Number of biogas plants and installed el. power in Germany and Austria. For better comparability the values for Austria were multiplied with a factor F equalising the different sizes of both countries (Schön et al. 2007).

2.3 Geothermal energy (GE)

2.3.1 General

Geothermal use is commonly divided into two categories: electricity production and direct application. Direct application of GE can involve a wide variety of end uses, e.g. district heating and air condition systems. Four types of power plants are commonly used to generate electrical power from GE depending on temperature, depth, and quality of the water and steam in the area. Dry steam, flash steam, and binary-cycle systems use either steam or hot water from underground to drive a turbine that spins a generator. Enhanced Geothermal Systems (Hot-dry-rock systems) utilise water that is pumped into hot rocks in the earth, rather than harvesting hot water already stored in the earth.

Geothermal exchange heat pumps are used for direct application of GE and can be used basically everywhere because they are suitable for low-temperature resources (UNDP 2000). These pumps utilise the Earth's ability to store heat in the ground and water masses as heating and/or cooling sources with the help of heat exchangers and loop systems containing refrigerant. Applications range from large plants for district heating to on-site exploitation for single houses.

2.3.2 Energy potential

GE is sparsely exploited in Austria. By 2003, only twelve district heating plants were in operation providing 41.5 MW thermal power. Two of the plants are operated in hybrid mode, producing electricity via ORC-turbines (3 GWh in 2006). 160,000 heat pump plants (approx capacity. 834 MW, annual heat output of 1,767 GWh) used for service water treatment (approx. 77%), heating purposes, heat recovery, and air dehumidification were in operation by 2001 (AEA 2003, e-control 2007). Regarding energy efficiency, direct use of GE has a much higher degree of efficiency (50–70%) than electricity production with 5–20% (UNDP 2000).

On the basis of the current economic and geological frame conditions, Austria's total geothermal potential is in the range of 2,000 MW of thermal energy and about 7 MW electricity AEA 2003. With regard to direct geothermal exploitation of ground and surface water a study for the Alpenrhein region (comprises parts of Austria, Switzerland and Liechtenstein) was conducted (Rauch et al. 2003). In this region an energy quantity of 150 GWh per year is extracted from the groundwater for heating and cooling purposes today. Assuming an induced temperature change of 1°C, an additional, theoretically utilisable potential of 1900 GWh can be determined. However, the limiting factors of hydraulic and thermal short circuits as well as feasible water abstraction restrict this potential to 300 GWh.

2.3.3 Aspects in Alpine regions

Generally, geothermal power plants are unaffected by changing weather conditions and diurnal variations. Thus, they are able to provide baseload power. However, upper reach regions of Alpine rivers can be favourable for geothermal applications using groundwater as aquifers consist of material with a rather high permeability.

2.4 Solar energy (SE)

2.4.1 General

SE comprises the following forms of energy:

- Photovoltaic SE is the direct conversion of sunlight into electricity utilising the photovoltaic effect: of generating free electrons from the energy of light particles (UNDP 2000).
- Solar thermal electric power plants generate electricity by converting SE to heat in order to drive a steam turbine in a thermal power plant.
- Low-temperature SE is the direct conversion of sunlight into low-temperature heat (up to 100°C). Such systems can be sized for single houses or for collective buildings and district heating.

Because solar electricity and heating offer an intermittent source of energy, most standalone systems are equipped with a storage unit to provide energy during the night or during days with insufficient sunshine.

2.4.2 Energy potential

According to (e-control 2007), at the end of 2006, photovoltaic systems with a total capacity of about 36 MW were in operation in Austria, feeding an annual output of about 13 GWh to the public grid. This equals a share of less than 1% of the country's electricity production. With 774 GWh (2,785 TJ) in 2001, solar thermal power also made minor contributions to renewable energy supply. There were 2,500 million m^2 of solar collectors in operation: 24% for swimming pool heating; 75% for water and space heating and 1% for drying biomass products (IEA 2004). Reported energy efficiencies for photovoltaic cells range between 5–30% (UNDP 2000; Verbund 2006).

2.4.3 Aspects in Alpine regions

Highest energy outputs could be gained for PV sites at higher altitudes due to clearer sky and snow reflection, better cooling of the panels through lower temperatures and higher wind speeds. This especially applies in fall and winter when haze and fog cause less energy output in the valley (Bergauer-Culver & Jaeger 1998). On the other hand, there are only few non-valley sites which could be quantified as feasible because of factors like site development costs, available space and impairment of nature or landscape.

2.5 Wind energy (WE)

2.5.1 General

Electricity from wind power (offshore and onshore) is generated by converting the rotation of turbine blades into electrical current by means of an electrical generator. The power output of a turbine is proportional to the cube of the current wind speed. The annual energy output of a wind turbine is determined by such parameters as average wind speed, statistical wind speed distribution, turbulence intensities, and roughness of the surrounding terrain (UNDP 2000).

Negative environmental aspects connected to the use of wind turbines can include acoustic noise emission, visual impact on the landscape, impact on bird life, moving shadows caused by the rotor, and electromagnetic interferences.

2.5.2 Energy potential

By end of 2006, 127 windparks (> 600 turbines) with a capacity of 953 MW and an annual output of 1,737 GWh were in operation in Austria (e-control 2007). Thus, Austria ranks sixth in the EU with installed wind power per capita and first among the landlocked states. This entails relatively high production costs and subsidy requirements compared to states with a shoreline.

The main problem with WE is the fluctuation in generation due to weak winds or storm shut down. This also applies when the plants are distributed over large areas and has significant repercussions on the European electricity system (UCTE 2005). Consequently, conventional power plants have to backup electricity demand which raises further costs.

2.5.3 Aspects in Alpine regions

Besides offshore sites, mountainous regions are preferred locations for wind farms due to reduced air viscosity and the phenomenon of topographic acceleration which can make large differences to the amount of energy that is produced. Investigations revealed some potential sites for WE in Tyrol, all located above 1,500 m of altitude. Development of this sites would involve difficulties like accessibility, grid incorporation, competing land uses and landscape aspects (ADTL 2003).

3 Conclusions and discussion

Renewable energy generally has a positive effect on energy security, employment and on air quality. But in the long term RES must achieve cost-competitiveness with conventional fuels to reach a permanently high share in the energy mix. For Alpine regions there are some distinctions regarding applicability and potentials of RES. A further expansion of HP as for example agreed by the Tyrolean government is intended to ensure a higher independence from energy imports and emission-free energy production but of course holds the risk of ecological impairments. There are potentials for BE for instance in small-scale agricultural biogas plants. In general, it should be noted that further expansion of BE can lead to contentions between acreage for food and energy crops and a subsequent increase of food prices. Regarding GE in Alpine valley settlements, it can be stated that there is plenty potential especially for decentralised heat pump systems in business and industry facilities. The same applies for solar thermal applications. The economic efficiency of photovoltaic electricity currently depends to a high degree on governmental incentives. Generally there are adverse effects on solar energy facilities in valley sites as insolation time is reduced by the mountains. As mentioned before, only hilltops are preferred locations for WE in Alpine regions. But in most cases disadvantages like development costs and impairments of the landscape outweigh possible benefits.

References

Amt der Tiroler Landesregierung 2003, Energieleitbild Tirol 2000–2020, Innsbruck

Amt der Tiroler Landesregierung 2007, Wirtschafts- und Arbeitsmarktbericht Tirol 2007, Innsbruck

Austrian Energy Agency 2003, Renewable Energy in Austria, Vienna

Bergauer-Culver, B. & C. Jäger 1998, "Estimation of the energy output of a photovoltaic power plant in the Austrian alps", Solar Energy, 62(5), 319–324

Bundesministerium für Landwirtschaft und Umwelt (Lebensministerium) 2007, Anpassung der Klimastrategie Österreichs zur Erreichung des Kyoto-Ziels 2008–2013, Vienna

De Toffol, S. , C. Engelhard & W. Rauch 2007, "Influence of climate change on the water resources in an alpine region", (Submitted for publication)

E-CONTROL (2007) Ökostrom sowie Energieverbrauchsentwicklung und Vorschläge zur Effizienzsteigerung [in German]. Energie-Control GmbH, August 2007, Vienna, Austria.

European Commission 2005, The support of electricity from renewable energy sources 2005, Brussels

Fachverband Gas Wärme 2007, Biogas: Potenzial in Österreich, on: http://www.klimaaktiv.at/, (1.09.2007)

International Energy Agency 2004, Renewable Energy: Market & Policy Trends in IEA Countries, Paris

Intergovernmental Panel on Climate Change (IPCC) 2007a, Summary for Policymakers. Climate Change 2007: Mitigation, Cambridge/New York

Intergovernmental Panel on Climate Change (IPCC) 2007b, Summary for Policymakers. Climate Change 2007: The Physical Science Basis, Cambridge/New York

Ragwitz, M., J. Schleich, C. Huber, G. Resch, T. Faber, M. Voogt, R. Coenraads, H. Cleijne & P. Bodo 2005, FORRES 2020: Analysis of the renewable energy sources' evolution up to 2020, Karlsruhe

Rauch, W., U. Stegner, F. Osterkorn, T. Blank, M. Gasser, A. Pfefferkorn, M. Obermayr, O. Wohlwend, G. Riedi & E. Hilbe 2003, Thermische Nutzung der Gewässer des Alpenrheintales, Bregenz

Schön, M.A., P. Phothilangka, A. Eladawy, H. Insam & B. Wett 2007, "Farmscale Co-fermentation of manure and organic waste", Proceedings of the IWA-workshop on anaerobic digestion in mountain area and isolated rural zones 5–7/Jun/2007, Chambéry

Union for the Coordination of transmission of electricity (CTE) 2005, Statistical Yearbook 2005, Brussels

United Nations Development Programme 2000, World Energy Assessment, New York

United Nations Framework Convention on Climate Change 1997, "Kyoto Protocol to the United Nations Framework Convention on Climate Change", Conference of the Parties on Its Third Session 10/Dec/1997, Kyoto

United Nations Framework Convention on Climate Change 2006, GHG DATA 2006-Highlights from Greenhouse Gas Emissions Data for 1990–2004 for Annex I Parties. United Nations Framework Convention on Climate Change, Kyoto

Verbund 2006, Verbund-Nachhaltigkeitsbericht 2006, Vienna

Wett, B., M. Schön, P. Phothilangka, F. Wackerle & H. Insam 2006, "Model-based design of an agricultural biogas plant: application of Anaerobic Digestion Model No.1 for an improved 4 chamber scheme", Water Science and Technology 55(10), 21–28