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Geothermal Resources for Development in Central America - Social and Economic Valuation, Present Use and Future Opportunities

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ABSTRACT

In Central America, growing population, expanding economies and new markets, result in an annual rate of the electricity demand of about 6% through the year 2020. This, together with the fluctuations in the world energy markets, require to develop more reliable domestic environmentally sound electrical systems, which are precondition for a sound social and economic development of the region.

Geothermal energy can provide such a stable electricity supply, in contrast to many alternative domestic renewable energy resources, such as climate event dependent hydropower, which covers actually about half of Central Americas electricity demand. However, the huge regional geothermal potential of about 8.8 GW using today's technology, and about 13.2 GW capacity potential "enhanced technology" for power generation, which exceeds the entire electric capacity installed in Central America in 2003 - about 6.5 GW - is practically unused (0.4 GW installed geothermal capacity; 2003).

However, instead of accelerating the development of indigenous, renewable energy resources, El Salvador, Honduras and Nicaragua have become more dependent on imported fossil fuels to supply their growing electricity demand. On the other hand, Guatemala is focusing on a large increase of hydroelectric power production, and Costa Rica is depending on an over-developed hydroelectric power program, which it tries expand in future even more. This makes the electricity generation of Guatemala and Costa Rica very vulnerable to climate events as droughts and other natural phenomena. So it becomes evident, that geothermal energy, an alternative to hydropower, which is not dependent on climatic events, has yet to receive the attention it deserves.

The analysis of the economic, social, and environmental benefits of geothermal energy in the Central American region compared to fossil fuel resources and to other renewables as hydropower, wind energy and solar energy, shows that geothermal energy has numerous direct and secondary benefits. However these benefits are generally not considered by national decision makers, who often only consider - as private investors do - only purely economic benefits of energy projects. They need to include social costs and benefits of geothermal energy generation - expressed in monetary terms - to make investments in energy projects, which are beneficial in a social perspective and so to contribute to establish a base for the social and economic development of Central American region.

1. INTRODUCTION

The decade of the 1990's brought peace and significant economic growth to the Central American region. Related expanding economies and new markets, together with growing population and increasing living standard all contribute to an increase in electricity demand at an annual rate of about 6% through the year 2020. This, together with the need to avoid increasing imports of fossil fuels and so prevent negative impacts from fluctuations in the world energy markets will require the development of more reliable domestic environmentally friendly electrical systems. This requires encouraging the development of renewable domestic energy resources.

Geothermal energy represents such an alternative source providing simultaneously additional benefits compared not only to fossil fuels but also to hydropower. Geothermal resources of Central America are huge. So with exception of Belize and Panama, in all countries all other energy sources, which are actually used for electricity generation, could theoretically be substituted by geothermal energy. However this huge geothermal potential of about 8.8 GW capacity using today's technology (13.2 GW using "enhanced technology", Gawell et. al., 1999), which exceeds the total installed electric capacity of about 6.5 GW (2003) is underused. So in 2003, only 0.4 GW were used for geothermal power generation. This contributes 7% of Central Americas total electricity generation (28090 GWh, 2000), which is predominantly generated by hydroelectric projects (50%), followed by thermal (41%) (Fig. 1). The respective total installed capacity was 6438 GW, composed by 49% hydroelectric, 43% thermoelectric, and 6% geothermal (Fig. 2).

The estimate of Gawell et al. (1999) corresponds to a geothermal electricity production of 42,000 GWh/year, and is equivalent to the burning of 3.7 million tons of fuel oil/year or 7.1×10^{12} m^3/year of natural gas. This potential geothermal generation is about two times higher than the power consumption of the region, which was 28,090 GWh/year in 2000 (Fig. 3). Considering an average annual energy demand growth rate of 6%, these reserves would be able to cover the power demand of the region for the next two decades solely (Fig. 3). The future introduction of the binary fluid technique, which makes geothermal resources of lower enthalpy suitable for power production, would double this potential. Additionally it must be considered that the aforementioned geothermal potential comprises only the actual known geothermal reserves, whereas the real regional reserves are expected to be even higher.

Thereby the energy mix shows country-dependent variations and trends. So El Salvador, Honduras and Nicaragua have become more dependent on imported fossil fuels to supply their growing electricity demand, instead of accelerating the development of indigenous, renewable energy resources. Guatemala increases significantly its hydroelectric power production, and Costa Rica is depending on an over-developed hydroelectric power program, which generates 82% of its national electricity (2000). This strong dependence of hydropower makes both of these countries very vulnerable to droughts and other natural phenomena. However, geothermal energy, which is not dependent on climatic events, has not yet received the attention it deserves as an alternative for hydropower.

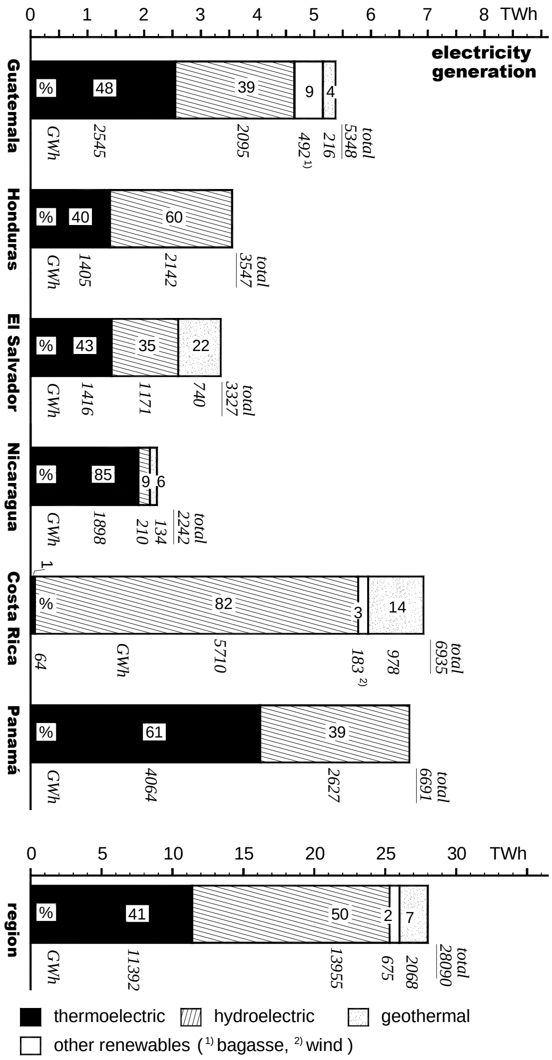

Figure 1. Central America: Sources of electricity production in 2000.

The present paper compares the economic, social, and environmental benefits of geothermal energy with fossil fuel resources and other renewables as hydropower, wind energy and solar energy. Considering the national demand and energy plans of the different Central American countries, it addresses social costs and benefits of geothermal energy productions - in monetary terms - and discusses reasons why the public and the private sector may avoid investments in geothermal energy production although the investments have numerous social benefits.

2. GEOTHERMAL RESOURCES AND DEVELOPMENTS

The commercial development of the geothermal resources in Central America was and is strongly influenced by changing interests and energy priorities of the different countries and the different national governments. It is also strongly driven by the restructuring of the energy sector which is combined with changing from public to private energy institutions (Bundschuh et al., 2002). At present, commercial geothermal exploration exists only in Guatemala, El Salvador, Nicaragua and Costa Rica, amounting in 2002, 4, 22, 6 and 14% of total national electricity grid respectively, hence making El Salvador to the most geothermal energy dependent country in the world.

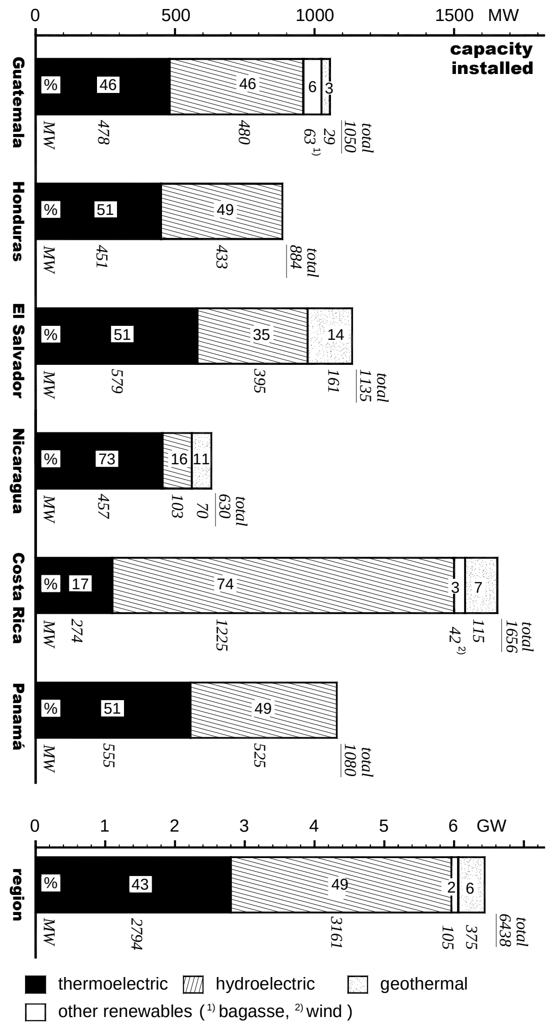

Figure 2. Central America: Sources of installed capacity for electricity generation in 2000.

Due to ongoing deregulation and privatization, coherent national energy plans do not exist. The present trend toward regional planning and the proposed natural gas pipelines makes the forecast of the future use of different energy sources in individual countries difficult. In the following the insufficient role of geothermal energy in the framework of national energy demand and expansion plans shall be shown for the case studies of Costa Rica, El Salvador, and Nicaragua.

Costa Rica: In Costa Rica, total electricity production was 6718 GWh in 2001 (Fig. 4), which was covered by hydropower (84.6%), followed by geothermal (12.2%), and wind (2.7%). According estimates of the national electricity entity ICE, the country's power sector needs investments of about US$ 3000 million by 2011, to satisfy the electricity demand which is forecasted to grow at an annual rate of 4.8 to 6.1% during the 2000-2020 period (Instituto Costarricense de Electricidad, 2001). The National Energy

Plan includes the installation of 29 new power plants, predominantly hydroelectric projects (Instituto Costarricense de Electricidad, 2001), resulting in an extremely high dependence on hydropower. According to ICE's plans, Costa Rica will maintain its present energy mix for the next 15 years, allowing the forecasts of installed capacity and power generation by source shown in Figure 4.

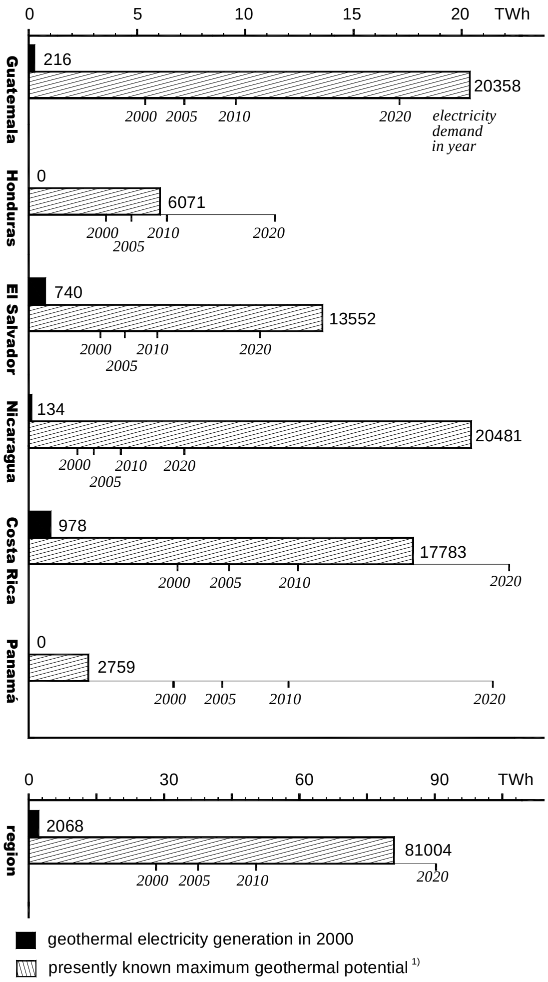

Figure 3. Central America: Geothermal electricity generation and power demand in the year 2000 in relation to future demand forecasts and estimated maximum geothermal potentials; [1)] Geothermal potentials are calculated from estimates from Gawell et al. (1999) using a plant capacity factor of 0.7.

El Salvador: At the end of 2001, El Salvador's installed generating capacity connected to the high-voltage grid was 1117.6 MW (Fig. 5). During that year, 3973 GWh were generated (47.8% thermal, 29.5% hydro and 22.7% geothermal). The electricity entity of El Salvador CEL estimated an annual averaged electricity demand growth between 4.1 and 7.35% for the next 15 years (Fig. 5). Since deregulation, no organization has produced a national energy plan, but using previous data, historic and future development of installed capacity and electricity production can be given as shown in Figure 5.

Nicaragua: In 2002, the total installed electricity capacity in Nicaragua was 653 MW, and total electricity generated in 2001 amounted to 2522 GWh (81.5% thermoelectric; 7.9% hydroelectric; 7.9% geothermal), (Fig. 6). The national electricity entity INE estimated a 6% per annum growth in electricity demand over the next two decades, which requires to extent capacity to 1179 MW. By 2005 Nicaragua's installed capacity will increase from 653 MW to 725 MW, reducing thermoelectric and increasing geothermal, which then will increase from 14% in 2002 to 24% in 2005 (Comisión Nacional de Energía 2001), (Fig. 6). For the energy project planning of the period 2006-2010, Nicaragua has developed different scenarios (Fig. 6). The amount and type of sources to be used depend on the construction of the SIEPAC regional electricity interconnection line and the natural gas pipelines projects from Guatemala or Colombia/Panama. In all scenarios, the contribution of geothermal to the country's total installed capacity will be similar ranging between 22 and 28%.

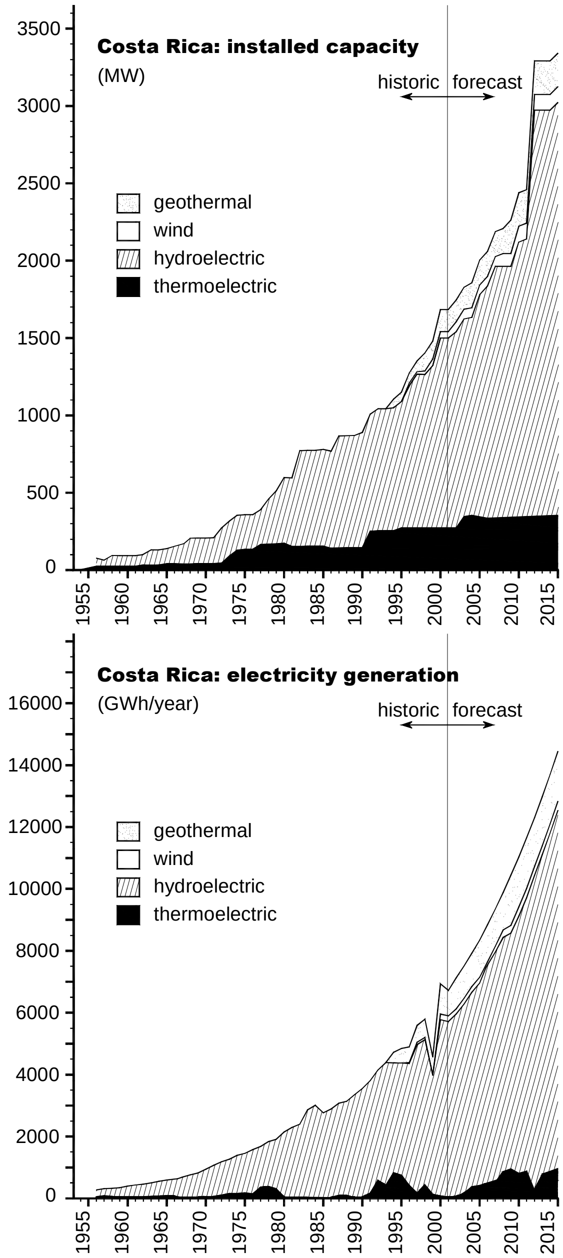

Figure 4. Growth of installed capacity and electricity generation in Costa Rica by source (modified from Bundschuh, 2002).

3. INTEGRATING DEVELOPMENT ASPECTS IN THE VALUE OF GEOTHERMAL ENERGY

The future development of the Central American countries is linked to possibilities of economic growth, which depend on availability of energy. The increasing regional electricity demand (annual average growth 6%) may theoretically always be covered by fossil fuel imports, but that makes countries to increasing extent vulnerable to shifts in world energy markets. Hence, domestically available and environmentally friendly energy sources to provide a stable supply of energy, as it is vital to the development of the regions countries, must be found and used. The development of these alternative energy sources cannot be evaluated only with reference to expected direct monetary costs and benefits, but it must be considered that a stable energy supply is a key factor in the transition from a risky low-income country to a developed economy, better integrated in the world economy, and challenged with respect to environmental issues.

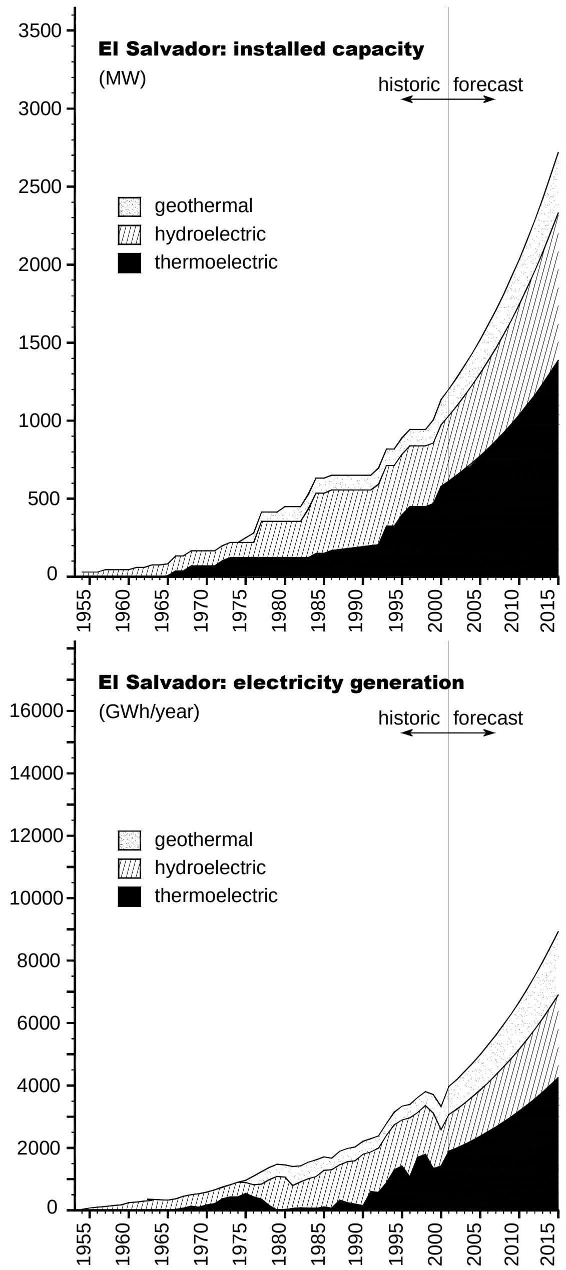

Figure 5. Growth of installed capacity and electricity generation in El Salvador, by source. Forecasts are based on a 6% average annual growth in electricity demand and no change in the present energy source mix (modified from Bundschuh et al., 2002).

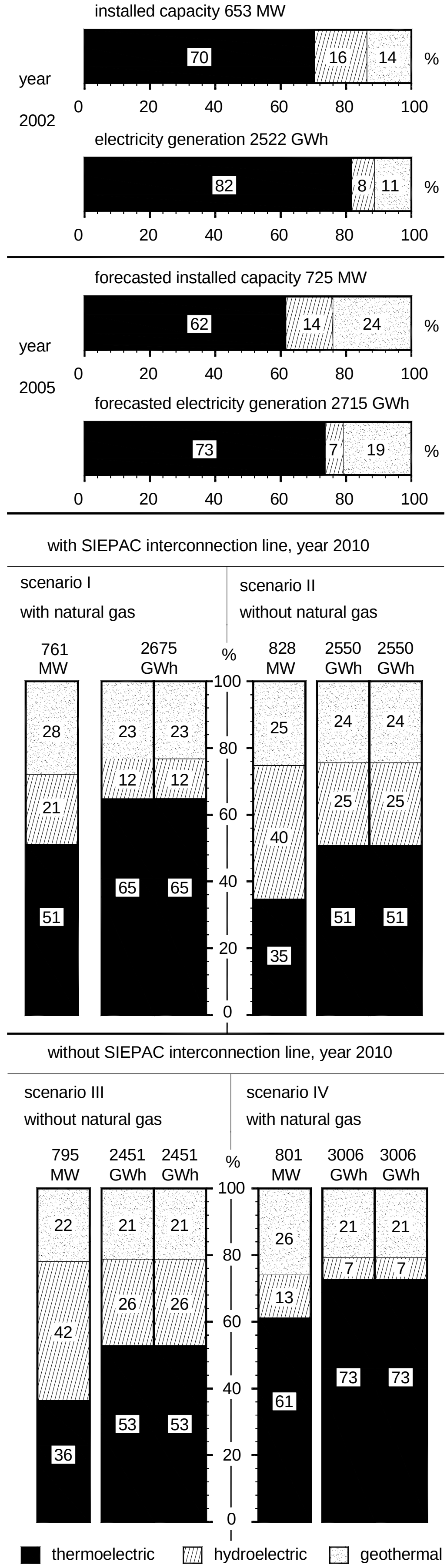

Figure 6. Installed electrical capacity of Nicaragua (2002) and energy expansion plans by source (on base of data from the Comisión Nacional de Energía 2001; (modified from Bundschuh et al., 2002).

If these factors are not integrated, the evaluation of alternatives to increased imports of fossil fuels will usually be made by pure economic considerations: (1) costs of developing alternative energy systems, and (2) risk evaluation. Thereby, in practice, the combination of high capital costs and uncertainty in respect to energy prices often disfavors domestically produced clean renewable energy resources, such as geothermal energy and the value of the clean energy resources as alternative to fossil fuels will be subject to the uncertainties in the world market for fossil fuels.

Although the integration of a wider scope of social impacts is important when evaluating alternative energy sources, the importance of monetary costs and investment benefits should not be underemphasized. As all developing countries, those of Central American are faced with financial restraints, uncommon to developed countries. Hence it may not be sufficient to show social benefits of clean energy sources, such as a reduced dependency of energy imports if these benefits do not enter into the accounting of the fundraiser.

Compared with fossil fuel imports, the most important social benefits of alternative domestic energy resources, as geothermal are: (1) the implied enhanced security of the energy supply, and (2) avoided environmental impacts. From a purely economic point of view, the risk of increased dependency on energy imports may be translated to uncertainty in fossil fuels prices. Additionally, the consequences of a sudden energy supply shortage, which causes a rapid increase in prices, may have serious indirect impacts on the entire national or regional economy.

Fossil fuel imports and uncertainties in the fossil fuel markets have quite different significance for private investors and for national authorities. To a private investor, the uncertainties reflect uncertain cost in the imports alternative, and a corresponding uncertainty in the value of the domestic energy alternative. Thereby it must be considered that fluctuations in world markets for fossil fuels do not necessarily affect the relative values between fossil fuels and other energy sources as geothermal because they are all affected by the same uncertainty. Reason is that in the case that fossil fuels are expensive, the value of the domestic alternative is high and if the world market price of fossils is low, the domestic alternative has a low value, too. However, there exist other important factors for private investors, which may be of disadvantage to domestic geothermal alternatives as (1) a high capital intensity of alternative energy production, which involves a considerable risk to the investor, and (2) uncertainties about technology performance.

In contrast, for the national authorities, imports of fossil fuels involve disadvantages, which private investors may neglect. So in contrast to private investors, they consider high world market prices of fossil fuels as disadvantage, since they affect negatively the national economy. Hence, in economies, which depend on energy imports, high world market prices of fossil fuels may lead to long-term recession. This disadvantage can be overcome by developing domestic energy resources as geothermal, which may contribute to stabilizing the domestic energy market. In the case of low world market prices, no positive impact on national development occurs as it may be expected. Reason therefore is that in this case all countries are subject to low prices, and the countries depending on fossil fuel imports do not gain from low energy prices relative to other countries. Therefore, the interpretation of "good news" and "bad news" are likely to be opposite for a private investor and decision makers from national authorities.

Additionally, and also in contrast to private investors, national authorities must consider the externalities of fossil fuel consumption. Thereby environmental impacts, in particular on air quality, which are closely related to fossil fuels and their social and economic consequences, are of particular interest. Although a poor environmental standard does not necessarily affect the economy directly, it may result in significant costs to the society in terms of poor health, and damages to vegetation and buildings. The usual proposal in industrialized countries to make private agents act in an environmentally acceptable manner is to impose restrictions on the sources of pollution, e.g. through special charges. However, such restrictions are quite uncommon in developing countries, since the major polluters are often the large industries, which represent the main potential for future economic growth. Therefore in Central America, instead of charges on the use of fossil fuels, it is more appropriate to develop incentives for private and public sector investments in clean energy projects. Additionally, the national authorities must increasingly consider global environmental issues, notably climate change, which in the past was mainly caused by greenhouse gas emissions of the developed countries. However it is recognized that in the future the developing countries will become the largest emitters of greenhouse gases, and that therefore global warming cannot be mitigated unless developing countries take an active part.

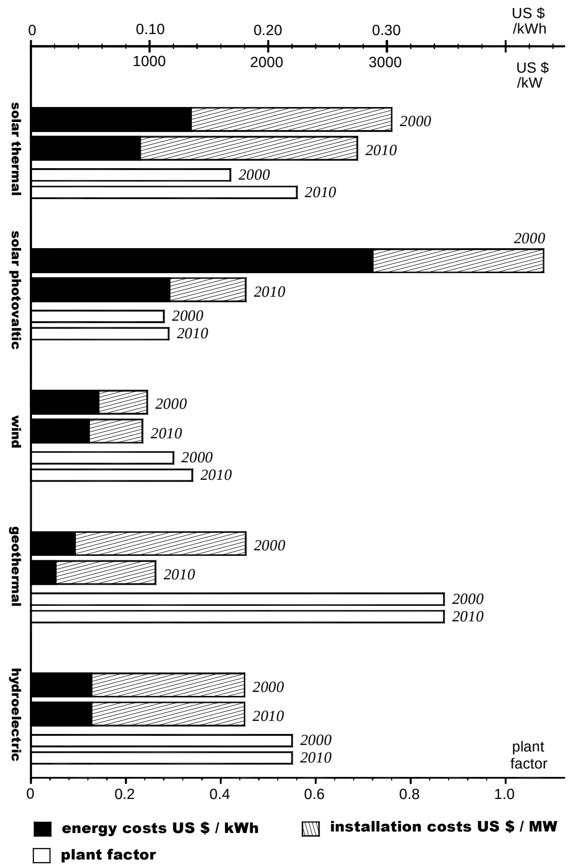

Figure 7. Comparison of installation costs, electricity costs and plant factors for different renewable energy sources for the years 2000 and 2010 (source: Energy Information Agency 2000; Instituto Costarricense de Electricidad 2001; costs for hydropower are based on Costa Rican conditions), (modified from Bundschuh et al., 2002).

4. COSTS, RISKS, AND FINANCING ISSUES

Under the present market conditions of Central America, the further development of geothermal energy resources can only take place if they are cost-competitive. Thereby geothermal must compete against fossil fuels and hydropower, which generate about 41% and 50% of the region's total electricity generation respectively.

Geothermal versus hydro: In Central America at present, the costs per installed kW are similar for geothermal and hydro, but by 2010, the installation costs (capital costs) for geothermal plants will be about half of those of a hydroelectric project (Energy Information Administration 2000; Fig. 7). Additionally it must be considered that geothermal plants have a much higher capacity factor (around 0.87 or more) compared to hydroelectric plants (around 0.55, but often lower). Considering the overall cost of the electricity produced by geothermal plants costs are much lower than that from hydroelectric plants and will become much cheaper in the future (Fig. 7).

Geothermal versus fossil-fuels: Installation costs of fossil-fuelled power plants are significantly lower than those of geothermal and hydroelectric plants. Depending on the used fuel type and plant size, it varies between 300 and 900 US$/kW. However it must be considered that by the year 2010, the installation costs for geothermal plants will be significantly reduced to about 1000 US$/kW (Fig. 7). Considering the fossil fuel energy costs of about 0.05 US$/kWh, these values are similar to hydropower plants but more expensive than geothermal plants.

Geothermal versus other renewables (solar, wind): During the next decade, solar energy will not become economically competitive. Wind energy has lower installation costs than geothermal and hydropower. The cost of the wind-produced electricity is similar to that of hydropower, but much higher than those for geothermal. When considering wind energy projects, also the disadvantage of their short lifetime, about 15 years, which is less than half that of geothermal and hydropower plant must be considered. Also the capacity factors for wind projects are very low (around 0.3; Fig. 7) compared to other power plants, especially geothermal.

The economic viability of geothermal projects can be shown for the case of Miravalles plant (Costa Rica). The sale of electricity generated by Miravalles Unit 1 amounted to US$ 188.96 million for the period 1994-2000 (Moya & Fernández 2001), which means that the initial investment of US$ 248.8 million are returned during 2004. This proves that investment costs for a geothermal plant can be returned without one decade (not considering other costs as capital interests and devaluation). Taking into consideration, that the capital costs for the Miravalles Unit 1, were about 4500 US$/kW installed, and that they are about half in the year 2002 and expected to be about a quarter in the year 2010, the time of investment return will be correspondingly decreased.

Advantage of a capital-intensive production - as it is geothermal - is that future costs may be regarded as relatively certain, and that the plant - once it is financed - may be operated at very low costs. This implies a relative gain in times when the fossil fuels price is high and so benefits geothermal plants compared with fossil fuel power plants. Additionally to the relative gain in times of high fossil fuel prices an absolute gain may rise, because the price of energy follows the price of fossil fuels. If the fossil fuel price drops, similarly, a relative loss may occur. As consequently it could be expected that an investor who must decide between a fossil fuel and a geothermal plant with equal expected unit costs is indifferent between the two options as long as the fossil fuel price may equally well decrease as increase. Nevertheless, different composites of capital and operating costs results in a difference between the alternative investments. In times with low energy costs, the large capital costs related to geothermal do not allow significant cost reduction by decreasing production. In contrary, the production needs to be maintained to cover parts of the capital costs, and may result in significant financial deficits. This shows that the private investor overtakes a much higher risk, when investing in capital-intensive geothermal plants, compared to fossil-fuel plants.

Like private investors, which chose that investment alternative that gives the highest expected profits, many national public entities use the same criteria for energy decision making. However, this does generally not lead to the best social decision. Therefore national authorities need to include social aspects and benefits in their decisions.

5. ECONOMIC, ENVIRONMENTAL AND SOCIAL BENEFITS

5.1 Economic asset value of geothermal energy

For the estimation of the regional economic asset value of geothermal energy, the geothermal energy resources known at present are expressed in terms of fuel oil and natural gas equivalents, demonstrating clearly the importance of geothermal energy as a national and regional energy resource (Table 1). Based on a fuel oil price of 110 US$/ton, the annual economic asset value of geothermal reserves of Central America is about 1.2% of the region's GDP. The direct economic benefits of geothermal energy use may be demonstrated for Nicaragua, which spends annually about US$ 95,000,000 to import oil for electricity generation, corresponding to 4% of its GDP. Geothermal power plants could rapidly displace all thermal plants, which corresponded in 2002 to 70% of the total installed capacity for electricity generation, and so improve significantly the country's foreign trade balance.

Table 1. Economic value of Central American geothermal energy reserves.

Economic available geothermal capacity[1] (MW)	13,210
Potential geothermal production[2] (GWh / year)	81,004
Fuel oil equivalent (10^6 tons/year) [3]	7.11
Natural gas equivalent (10^9 m^3/year) [3]	8.35
Asset value (10^6 US$ / year) [4]	781
Asset value per capita (US$ /year) [5]	21.0
Asset value as percentage of GDP	1.15

[1] Maximum advanced technology potential (Gawell et al. 1999), [2] based on a plant capacity factor of 0.7; [3] fossil fuel heat value 11.4 MWh/t fossil fuel; natural gas 9.7×10^{-3} MWh/m^3 natural gas (Organization of American States 2001); [4] based on a fuel oil price of 110 US$/ton; [5] based on 2001 population and GDP of 2002.

5.2 Benefits through emission reduction

5.2.1 Potential of emission reduction

The CO_2, SO_x, and NO_x emissions of geothermal plants, amount less than 2% of the emission from oil-fuelled power plants (UNFCCC 1997). On average, geothermal plants emit 0.893 kg CO_2/MWh, whereas the emission of oil-based plants amount 723 kg CO_2/MWh (diesel fuel emission factor; UNFCCC 1997). For SO_x the corresponding values are 0.16 kg/MWh (geothermal) and 4.99 kg/MWh (oil fuelled plant; UNFCCC 1997).

The country wise and regional present and future fossil fuel consumption for electricity generation and related CO_2 emissions and so the possible emission reduction resulting from a replacement of fossil fuel fired plants through geothermal plants was estimated by Bundschuh et al. (2002) for the 2000-2020 period (Fig. 8). The forecasts of this author are based on the countries national energy plans, and where these are not available, predictions were made assuming (1) an annual growth rate of electricity demand of 6%, (2) no change of the actual energy source mix, and (3) the use of the same technologies as presently used. Based on these simplified assumptions, this forecast clearly indicates an exponential increase in CO_2 emissions during the next decades, rising from the present about 10 million tons to 30 million tons in 2020 and 96 million tons in 2040. Figure 8 also indicates that fossil fuels used for power production could be mostly substituted by geothermal generation.

A concrete example for the potential reduction in CO_2 emissions is the planned El Hoyo-Monte Galán geothermal project (Nicaragua). Considering an annual generation of 520,000 MWh and a lifetime of 38 years, Nicaragua's carbon dioxide releases to the atmosphere would be reduced by 14 million tons when compared to fossil fuel fired plant of similar capacity (UNFCCC 1997).

5.2.2 Economic evaluation of emission reduction - Mitigation of local environmental impacts

The socio-economic impacts of air pollution, which may (1) affect the human health, (2) results in material damage and (3) lead to crops losses, depend on a variety of factors, as the composition of pollutants and the density of exposed recipients. Although, in the past, most concern was attributed to urban air pollution, in recent years increasing attention has been paid to secondary effects of air pollution, as tropospheric ozone and secondary particles, which spread out over much larger areas than previously expected ones restricted to the near vicinity of the source.

Since there exist no suitable studies of economic evaluation of emission reduction through reduction of fossil fuel power plants from the Central America region, the following figures from a case study of Hungary (Aaheim et al. 2000, Aaheim & Bundschuh, 2002), shall be discussed. The Hungarian case was selected since it is the only one, which shows the difference between assessments made with a national perspective (top-down) and one made with the perspective of private investors (bottom-up).

Although these data are not directly transferable to the Central American situation, they give a first idea of the possible economic values of secondary benefits of emission reduction in Central America, which depend on a wide range of local factors, including the background level and composite of pollutants, the size and concentration of the population, and the cost of abatement measures, which are expected to be different in the example from Hungary and Central America. However, point estimates from Chile (Cifuentes et al., 2000), Brazil (Serôa da Motta et al., 2000) and Mexico (Borja-Abutto et al., 2000) indicate that the social benefits of health effects from energy saving measures has a similar distribution as in Hungary, indicating that a certain transferability of the results from the Hungary case study to Central America is given. The bulk of benefits (social cost reduction) from emission reduction from fossil fuel burning power plants relates to a reduction in the frequency of chronic bronchitis. Of minor importance are cases of acute respiratory symptoms and asthma, which are influenced by emissions. Reason is that the social costs related to these last mentioned diseases are smaller, and similar to the social value of improvements from better air quality to reduce more serious diseases, such as lung cancer, and deaths.

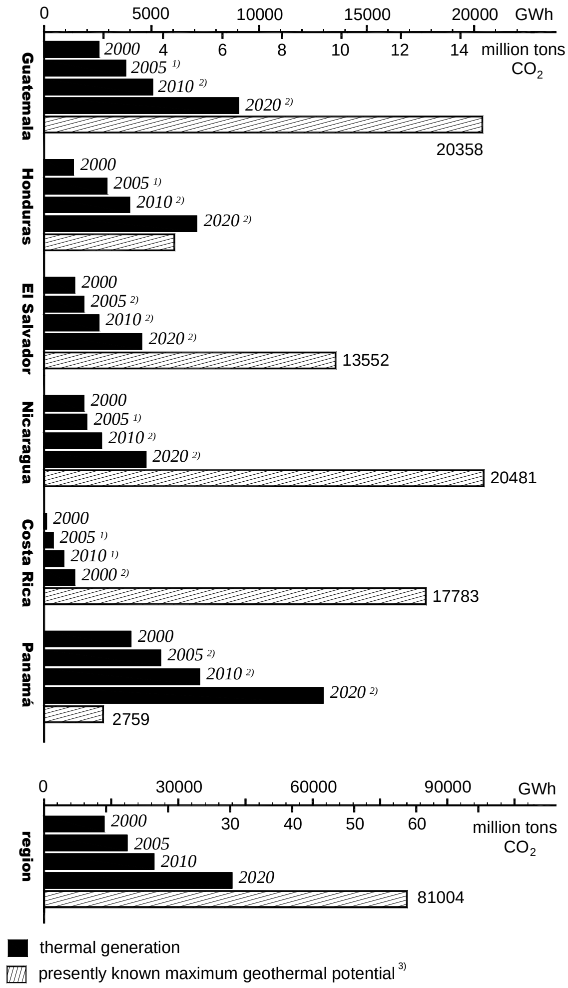

Figure 8. Thermal electricity production and corresponding CO_2 emissions. 1) Based on the energy plans of the individual countries, 2) based on a 6% annual growth in power demand and generation, and assuming that the energy mix will remain constant, 3) maximum advanced geothermal technology potential (Gawell et al. 1999), (modified from Bundschuh et al., 2002).

The economic value of improved air quality, and so the economic value of emission reduction is uncertain. In the Hungarian case, Aaheim et al. (2000) found that emission reduction or the replacement of fossil fuel electricity plants with clean energy plants would reduce material losses by annually 5.5 million US$/TWh and would lead to an increase in crops corresponding to annually 0.1 million US$/TWh.

The most substantial part of the benefits from better air quality results from an improvement in health standards. Air quality variations affect (1) the risk of death, (2) the risk of developing cancer, and (3) various respiratory problems. The quantification how reduced emissions may improve health standards is highly uncertain and depends on a variety of factors that are partly locally variable, such as population, population density, and weather conditions.

In spite of these limitations of transferability, some observations from the Hungarian case shall be given to indicate its importance for the Central American region and the need of corresponding detailed studies in this region.

The first observation is that the social costs through respiratory diseases are much higher than those through deaths and cancer are much rare compared to respiratory diseases. In the case study of Hungary (10 million inhabitants) for each TWh replaced by clean energy, (1) less than eight more people would survive or avoid cancer, (2) about 2% of the population would avoid acute respiratory symptoms, and (3) the frequency of asthma would be reduced by over 10%. These numbers clearly demonstrate that in Central American significant reduction of social and economic losses could be achieved if fossil fuel plants would be substituted by renewables as geothermal. This substitution becomes especially important, since electricity demand of the Central American region is exponentially growing during the next decades (Fig. 8).

The second observation is that the quantification of economic benefits from emission reduction is very difficult to assess, and that estimates depend on the approach used as it was shown for the Hungarian case, where Aaheim et al. (2000) compared three approaches, whose results are given in Table 2.

The *reduction in economic damages* approach is exclusively based on the "hard" economic benefits. Thereby benefits to materials and crops were calculated by the reduction in maintenance cost and increased market value, respectively, and health benefits were calculated as a combination of increased labor productivity from affected people and reduced labor costs in the health sector. This "hard" estimate considers that the only benefit from improved health is that society can get more production out of each person, and that the costs for medicines and care can be reduced. Without doubt, such estimation reflects is no realistic assessment of the value of being healthy. Due to that limitation, another assessment which is based on the valuation criteria *willingness to pay* for being healthy was performed. Nevertheless that this is the correct approach, this assessment faces severe difficulties. Principal difficulties are caused by the fact that preferences are not revealed from real market behavior and that the *willingness to pay* are only estimates at the current air quality level and do not consider that the *willingness to pay* will decrease if air quality increases. To overcome these difficulties, the value of improved health standard was introduced into an *economic model (macroeconomic assessment)* where estimates of the parameter *willingness to pay* were applied to parameterize demand functions for health.

The results from the three assessments (Table 2) prove that benefits of substituting fossil fuel plants by clean energy are high, but that quantification is difficult. The marginal benefits obtained from *reduction in economic damages* approach and the *willingness to pay* assessment, are 0.8 to 3.6 US cents/kWh, whereas the *economic model* based estimate is 2.6 US cents/kWh. The average benefit obtained from the model-based *macroeconomic assessment* is significantly lower than the other estimates. Reason therefore is that the *reduction in economic damages* and the *willingness to pay* approaches are only partial assessments, where all benefits are calculated in terms of costs and benefits. Therefore, the partial estimates are more comprehensive than the model-based macroeconomic estimate, but they are less informative. When evaluating the model-based result, it must be considered that the resources in the entire economy are being utilized more effectively.

Table 2. Economic benefits of improved air quality from reductions of 1 TWh from coal fired power plants in Hungary. Source: Aaheim et al. (2000).

Approach	Average benefit	Marginal benefit
	Million US$/TWh	US cents/kWh
Reduction in economic damages	8.0	0.8
Willingness to pay for improved air quality	36.4	3.6
Macroeconomic assessment	2.5	2.6

Considering these results, it becomes evident that the social value, of the replacement of fossil fuel plants (which cover actually about the half of Central Americas electricity demand) by renewable energy plants, expressed in monetary terms, is high, and must be considered in future national and regional economic and social planning.

5.2.3 The Clean Development Mechanism (CDM)

Although policy-makers attribute more attention to climate change than to any other environmental problem, up to now only developed countries are subject to proposed emission targets. However, the Clean Development Mechanism (CDM) of the Kyoto Protocol allows participation of developing countries. CDM is a tool, which enables developed countries to pay developing countries to reduce their emissions, and thereby obtain a credit on their own emission targets. This means that the emissions of greenhouse gases of developing countries have now obtained a monetary value, and may be traded. Another advantage for the developing countries is that these CDM projects, which are paid by the developed countries, will mostly comprise technology transfers to developing countries. Therefore, the CDM provides foreign investors with their need for additional motivations, and relaxes the financial restraints that seem to hamper the development of geothermal energy in Central America as well as in many other developing countries.

However, there are numerous problems related to the initiation of the CDM. It is e.g. difficult to quantify the emission cuts of a certain proposed CDM project, because it requires a counterfactual assessment of future emissions. Additionally, it must be considered that investing developed countries and the host developing country have different interests and priorities. So, investing countries are interested in emissions, while host countries are interested in development aspects of the particular CDM project.

Although it is difficult to predict the importance of CDM, it creates an additional value for producing energy without greenhouse gas emissions, and thereby contributes to enhancing the value of non-carbon energy as geothermal. Hence it assists to overcome some of the above mentioned obstacles for investments in domestic geothermal energy production in developing countries since the investing developed country has the full additional cost of the 'clean' alternative. Additionally, uncertainties related to the technical performance of new technologies may be reduced, partly because investing countries are already familiar with it, and partly since the responsibility is shared between the two countries.

Using the forecasts given in Figure 8, in the year 2020 the Central American region may reduce its CO_2 emissions by about 65 million tons if geothermal units substitute thermal plants. With a quota price at 5 US$/ton CO_2 , this results in direct financial benefits (not including ancillary benefits) of US$ 325 million or 0.35% of the region’s GDP (calculated from the 2002 GDP assuming an average annual GDP growth rate of 1.3%). Hence, the CDM may reduce investors' barriers to invest in capital-intensive geothermal plants.

In practice, in Central America (and worldwide), geothermal energy has not yet attracted much attention as an opportunity for CDM projects. In Central America exist several relatively small AIJ/CDM (AIJ Activities Implemented Jointly) projects on renewable energy related to hydropower and wind energy. Nicaragua is the only country, which applied for a geothermal AIJ project (i.e., El Hoyo-Monte Galán geothermal field), which was approved but had to be cancelled due to other reasons.

Considering all the advantages of CDM for implementation of geothermal projects, the question rise why investors do not show enough interest. Direct reason may be that the development cost of the geothermal field is too high. However, there are many other reasons that could be overcome with a better management from the national governments' side, and in the context of managing CDM projects in the international arena. At present, the CDM is predominantly a matter of bilateral cooperation between the developed country investor and the developing host country. As consequence, the full risk of a particular CDM project is imposed on the investor and the host country, putting a significant burden on unconventional energy options, such as geothermal energy. This obstacle may be reduced if all CDM projects are managed in a kind of international clearing house, with the aim of spreading the risk.

5.3 Benefits of geothermal versus hydroelectric power generation

Especially Guatemala and Costa Rica, plan to build a series of hydroelectric projects although these are sensible to climate related events, hence questioning the reliability of hydropower as a continuous, baseload energy source. For example in Guatemala in September 1999, after two weeks of rainfall and flooding, national electricity production became endangered and 100,000 persons had to be evacuated from areas downstream of the El Cajón hydroelectric project, which generates 60% of the countries' electricity. Hydroelectric projects are additionally affected in periods of droughts or low and variable rainfalls, which can significantly reduce outputs and send power prices higher during times of peak demand. So countries should not rely too much on hydropower to supply the electricity needs and hence they should reduce instead of increase its vulnerability to climate-related phenomena. This calls for promotion of geothermal energy, which is more reliable and would lead to a well-balanced renewable energy mix between hydroelectric and geothermal sources.

Additionally, the construction of hydroelectric dams has been widely criticized because of negative effects on the environment and local populations and hence environmental and social impacts must be carefully evaluated during planning of hydroelectric projects.

Compared to hydroelectric projects, geothermal projects have much less environmental and social impacts and generally are not affected by climate events. Additionally, geothermal installations occupy much less land. Since geothermal energy is - compared with hydropower - a constant and hence a very reliable energy source, it can be used optimally to supply base-load. Emissions from geothermal plants are very low compared to those of conventional fossil-fuel fired plants (see 5.2.1). To avoid environmental impacts, re-injecting the cooled waste geothermal waters back into reservoir at depth is required.

Since many Central American high-enthalpy sites are located in volcanic zones, which often include protected areas, the development of geothermal resources may require special considerations. This is especially valid in Costa Rica, where nearly the entire volcanic mountain range which includes all high-enthalpy geothermal resources is outlined as protected area. Examples are the Rincón de la Vieja and Tenorio volcanoes. The first is Costa Rica's most promising geothermal prospect with most of its geothermal resources located within a national park. Therefore the ICE has decided to restrict the exploitation activities to areas directly at the boundaries of the national park, a less likely successful target.

The visual impact of geothermal surface installations (pipelines and roads) is of special importance in the case of high-enthalpy areas, which are located in sensitive natural areas of tourist interest. These limitations do not apply for low and middle enthalpy geothermal resources. These resources cover much more extended areas compared to high enthalpy sites and they are not limited to the near vicinity of volcanoes. So their future use may take place in appropriate places, which are not in conflict with protected areas or environment in general, even they may be located near urban centers, where the impact is lowest and electricity demand is highest.

The probability of seismic events is similar for geothermal and hydroelectric projects, but social and economic consequences are quite different. Especially the downstream flooding caused by a dam failure may cause high losses in life and property, whereas those associated with the collapse of a geothermal plant are expected to be much smaller.

6. RESULTS AND CONCLUSIONS

The huge geothermal energy resources of Central America, which with exception of Belize and Panama, could be used to cover theoretically the present Central American electricity needs, including the increase of the next decades, are underused resources and market opportunities. Their appropriate development is hindered by regulatory, institutional, economic and financial barriers. This occurs although geothermal energy has substantial advantages in a social context compared with alternatives of fossil fuels and other renewables. They may provide a stable and clean domestic electricity supply in the regions countries.

The true potential of geothermal energy resources can be only used to satisfy an increasing percentage of Central Americas fast growing energy demand, if governments: (1) prepare the institutional and regulatory frameworks that would help to overcome the present economical and financial obstacles associated with geothermal projects, (2) create or improve sustainable renewable energies policies, and (3) consider the social value of geothermal resources by integrating geothermal energy in their development plans instead of considering them only from a purely market point of view. Therefore, the national authorities need to internalize the social costs of the so-called negative externalities of energy production.

Although that there are many uncertainties about the costs of environmental impacts (as those of fossil fuel plants) and the respective monetary values of their reduction, the social gains of geothermal energy may be significant. To implement environmental improvements in the decision-making of private and public investors in energy projects, the national authorities in Central America and in developing countries in general must introduce incentives for private investors as well as for public electricity institutions and their respective financing entities. Without such incentives, investments in traditional fossil fuel fired plants, especially in times with low fossil fuel prices will remain the option, which will be preferred in public and private investments, hence remaining an obstacle for sustainable, geothermal energy development.

Privatization or private sector participation becomes more and more important in Central America. Because of the high costs and risks of geothermal exploration and the high initial costs to develop a geothermal field, such private sector participation is very important. However, the review of the economic properties of geothermal energy production showed that the private sector may be reluctant about geothermal development. Principal reasons are (1) the high capital costs, which make the economy of geothermal energy plants more vulnerable to uncertainties in the energy market, and (2) the performance of the geothermal technology.

Considering the CDM as a mechanism to agitate further geothermal development, it becomes clear that it is an additional incentive for geothermal development. However it is related to different uncertainties for both, investors from developed countries and developing host countries. These uncertainties can be overcome if geothermal technologies becomes better known, e.g. by increased technology transfer from investor to host country within CDM projects, but especially by a management and co-ordination of CDM projects at international level and not as actually at bilateral level.

Additionally, capacity building and popularization of the geothermal energy issue is needed to establish awareness and acceptance of geothermal energy by politicians, decision makers, and society. Further on, there is need for institutional strengthening, human resources formation and to form awareness to consider geothermal projects as AIJ/CDM opportunities.

As result of previous observations and conclusions, the following recommendations for national energy policies can be derived for the distinct countries: Costa Rica, the country, with the most environment friendly electricity generation (99% renewables) of the region, should reduce its over-dependence on hydropower with its seasonal weather related problems. Costa Rica needs to favor a larger geothermal energy development and to aim a 1:1 relationship between hydropower and geothermal energy. Unfortunately El Salvador, Panama, Nicaragua and Honduras plan to cover most of their future increasing electricity demand by using fossil fuels, and Guatemala is expanding its hydroelectric sector. These countries should integrate renewable energy sources in their national energy plans, implementing thereby sustainable energy policies with incentives to all renewables, including geothermal and aim a sound mix of different renewables, and at the same time reducing fossil fuels uses to a minimum. By considering all ancillary benefits of geothermal energy, these measures would significantly improve the economic, social, and sustainable development of the countries and the region.

Summarizing, geothermal has a number of advantages over fossil fuels and other renewable energies, and should be the energy source of choice for the Central American region.

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