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## Leap-Frogging: A Way to Foster Sustainable Development in the Energy Sector

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**World Energy Council 16th Congress  
Conseil Mondial de l'Energie 16<sup>ème</sup> Congrès**

**Division 4 Energy for a Better Environment**

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**PS/SRD 4.3 Policies and Actions for a Better Environment**

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**4.3.15**

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A WAY TO FOSTER SUSTAINABLE DEVELOPMENT  
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**LEAP-FROGGING:  
UN MOYEN PERMETTANT  
DE FAVORISER UN DEVELOPPEMENT SOUTENU  
DANS LE SECTEUR DE L'ENERGIE**

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# **World Energy Council 16th Congress**

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### **4.3.15**

#### **LEAP- FROGGING: A WAY TO FOSTER SUSTAINABLE DEVELOPMENT IN THE ENERGY SECTOR**

#### **LEAP- FROGGING: UN MOYEN PERMETTANT DE FAVORISER UN DÉVELOPPEMENT SOUTENU DANS LE SECTEUR DE L'ÉNERGIE**

**AMELUNG; Torsten**

**RÜCKER; Ute**

**RAG Group of Companies, Germany <sup>1)</sup>**

##### **1. Introduction**

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In recent years, „Sustainable Development“ (SD) has become a major theme of economic policy discussions, dominating the 1992 UNCED-Conference in Rio de Janeiro. Although SD lacks a clear definition and conceptual precision, the debate on the sustainability of economic growth with respect to its environmental impacts has brought up two policy issues.

- The first is related to the question, whether industrialized countries can reduce the natural resource intensity of their economies without suffering substantial welfare losses in terms of absolute losses in income. Since industrialized countries account for a large share of worldwide natural resource consumption given their high share in world GDP - this question calls for short run policy actions.
- The second issue is associated with the key question in development economics, namely to what extent high economic growth rates in less developed countries (LDCs), newly industrializing countries (NICs), as well as countries in transition can be achieved without getting increasingly more dependent on the excessive use of natural resources.

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1) Thanks are due to Matthias Hessling (RAG, Essen) and Henning F. Amelung (Mercer Consulting, Washington D. C.) for comments that have improved contents and clarity of exposition.

This paper emphasizes the second issue and the impact of SD policies on the structural development of the energy sector and the coal industry in particular.

The next section yields a short overview on the requirements of SD strategies for the energy sector, which has been attributed a key role for infrastructure development and, thus, for economic growth. Thereafter, in section 3, we will address to the economic preconditions that have to prevail in order to run a SD approach in the energy sector. Finally, in section 4, we will survey the technical and economic potential for increasing the efficiency of energy use especially in the coal sector.

## **2. Implications of Sustainable Development Strategies for the Energy Sector**

### **2. Implications des stratégies de Sustainable Development (SD) pour le secteur de l'énergie**

In recent years there has been a growing awareness about the environmental and social impacts of growth-oriented development processes. Both, governments and Non Government Organisations (NGOs), have been looking for ways to maximize the net welfare impact of economic activities without losing sight of economic, ecological and cultural assets concerning a fair distribution of natural resources between generations (Munasinghe, 1993). In this respect, various policy strategies have been developed known as "Sustainable Development". The aim of these policies is to maintain high economic growth in the long-run without simultaneous and irreversible destruction of ecosystems. The first organization to express the idea of sustainability, although solely looking at simple systems of renewable energy resources, was the International Union for the Conservation of Nature and Natural Resources (IUCN, 1980) in 1980.

According to Repetto (1986), SD calls for a "development strategy that manages all assets, natural resources and human resources, as well as the financial and physical assets for increasing long-term wealth. Sustainable Development, as a goal, rejects policies and practices that support current living standards by depleting the productive base including natural resources, and that leave future generations with poorer prospects and greater risks than our own".

Each definition of SD stated previously, is subject to both social and environmental conditions. Although social aspects are very important, this paper focuses only on the environmental aspects, such as all environmental and natural assets. Though these assets can be hardly evaluated in terms of prices and economic value, they are part of a country's overall capital stock or wealth. Sustainability requires that this overall capital stock is maintained at least constant in the long-run.<sup>1)</sup>

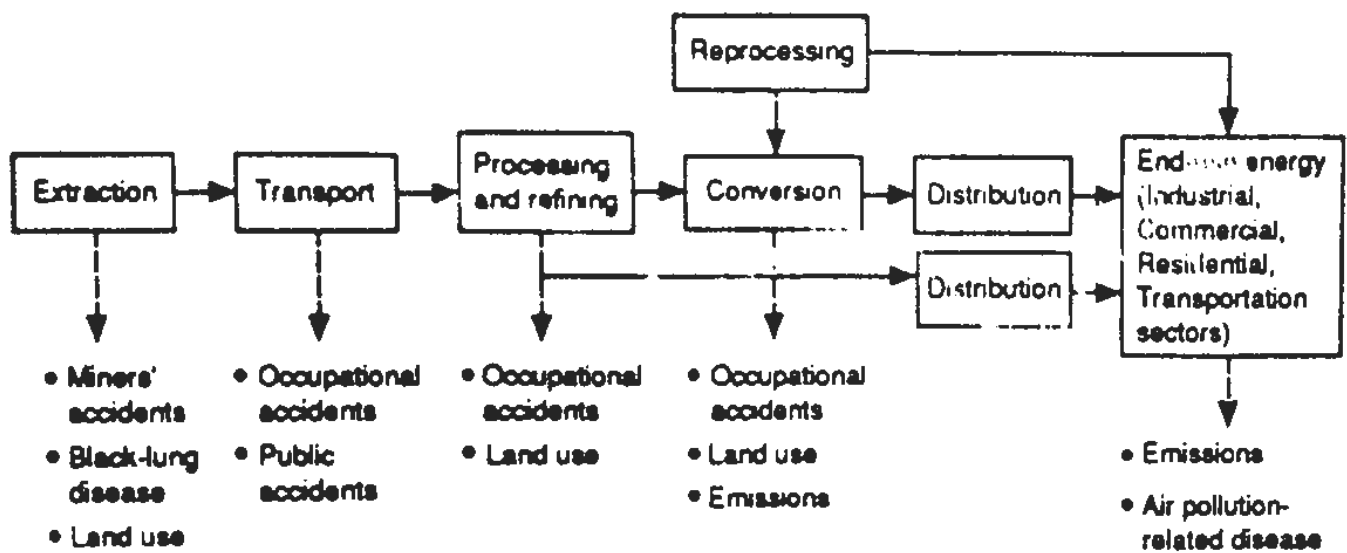
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1) Constancy may have several meanings. For instance, the Brundtland Report or the World Commission for Environment and Development, refers to the constancy of the physical capital stock (Lele, 1991). Another weaker definition of this concept refers to constancy as the total value of the overall capital stocks (Pearce/Barbier/Markandya, 1990). The definition used for the purpose of this paper is based on the substitutability of natural capital stocks for man made capital goods as well as financial capital (Amelung, 1992).

The energy sector affects the stock of natural assets in two basic ways:

- Approximately 90 % of the world primary energy supply is based on the extraction of non-renewable fossil fuels, which are part of the natural capital stock.
- Energy production and consumption and their resulting environmental impacts reduce the quality of the natural environment and cause economic and social costs at all stages of the fuel chain (see Figure 1).

Figure 1: Typical environmental impacts associated with each point in the fuel chain



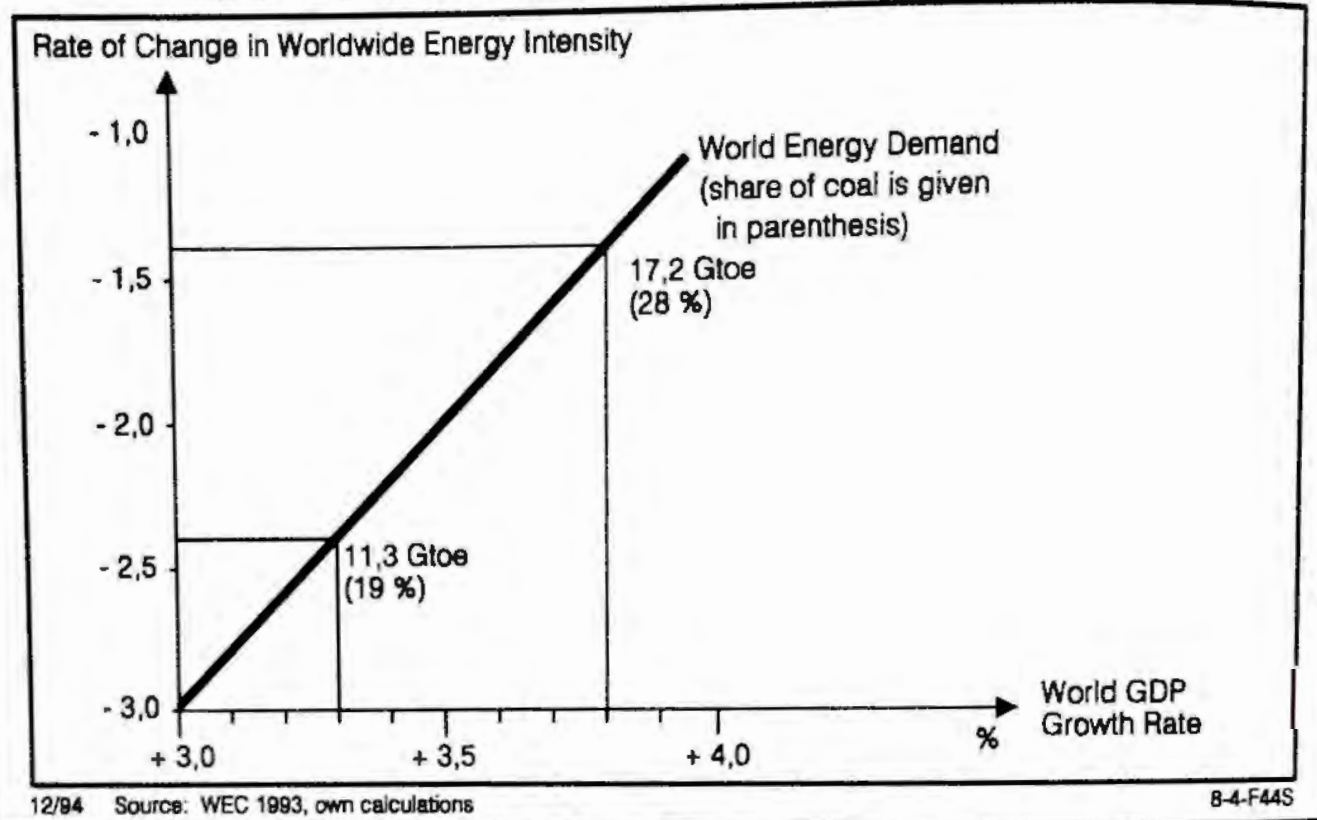
Source: Foell et al. [1981].

Both aspects impose serious restrictions on the future development of worldwide energy markets:

- Given high economic growth, which is required to satisfy basic needs in LDCs and NICs, energy demand is likely to double in the next 25 years (WEC 1993). This demand growth can be attributed to progress in industrialization and standards of living but also to population growth in the so-called Third World. According to these demand prospects, fossil fuels will maintain a considerable market share in the long-run. Even assuming excessive growth in the use of renewable and nuclear energy, this development implies a substantial absolute increase in fossil fuel consumption.
- The level of reserves, measured in terms of the production/reserves ratio, reveals substantial differences between different forms of fossil fuels. While coal has a range of more than 200 years, oil and gas account for 40 and 60 years respectively. Given these scarcities and the demand prospect especially in LDCs and NICs, it is inevitable that coal will become the most important source of energy. Thus, policies aiming at a substitution are short-sighted and non-sustainable in the long-run. The relationship between world energy demand and the share of coal on the one hand, as well as world GDP growth and energy efficiency on the other, is illustrated in Figure 2.



**Figure 2: Prospects of World Energy Demand in 2020  
as a Function of Efficiency and Economic Growth**

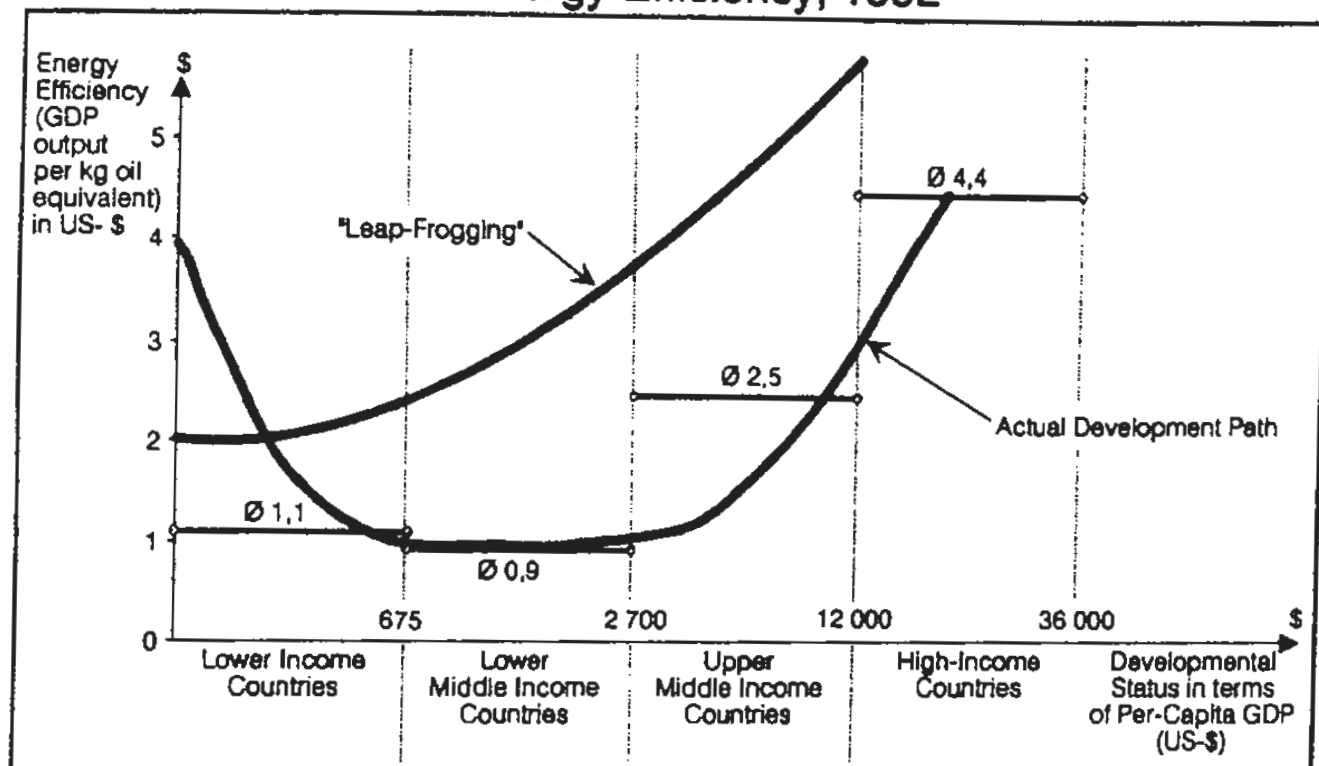


- Notwithstanding the different attitudes towards environmental issues, there are clear limits to an excessive use of fossil fuels. Energy-related activities (including the transport sector) are responsible for about 55 % of all anthropogeneous greenhouse-gas emissions worldwide. For example, total CO<sub>2</sub> emissions in the year 1991 amounted to 21 billion t. Three quarters of these are emitted by industrialized countries (Enquete-Kommission "Schutz der Erdatmosphäre", 1992, pp. 58). As the growth of energy demand is much higher in LDCs and NICs than in industrialized countries, the former are likely to account for half of the global CO<sub>2</sub>-emissions in 2020 (WEC, 1993).

Hence, rapid economic growth in LDCs and NICs, particularly in the Asia Pacific region, is accompanied by growing energy demand and associated environmental problems. It can be questioned whether LDCs and NICs should follow the historical example of today's industrialized countries, i. e. the fostering of economic growth through rapid expansion of fossil fuel consumption at a very low level of efficiency. SD in the energy sector calls for a strategy avoiding these „ex-post“ mistakes made by industrialized countries.

Within this context, one premise for a successful SD concept is to manage economic growth through more efficient and more careful use of energy. As **Figure 3** shows, the development of energy efficiency is a function of a country's developmental stage. Low income countries feature a comparatively low degree of energy efficiency due to lack of technology and use of traditional energy systems. However, this low level declines further, when countries enter the stage of industrialization. At this stage, growth in energy demand is much higher than GDP growth. This holds especially true for fast growing economies: in the 1982 - 1992 period the growth of energy consumption in South Korea, Malaysia and Thailand averaged 10 % per year.

Figure 3: The Relationship between Developmental Status and Energy Efficiency, 1992



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Source: World Bank; own calculations

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Reaching higher stages of the development process the degree of energy efficiency increases, thus leading to a decoupling of economic growth and energy demand. Progress in terms of a SD strategy means that LDCs leap over the most energy intensive and polluting stages of industrialization ("leap-frogging"). Leap-Frogging requires LDCs to adapt the technology and management practices exercised under the pressure of tightened environmental protection laws and energy price increases in the industrialized part of the world. If this know-how is made available to LDCs, they will install less polluting technologies from the onset and, therefore, be able to leap directly to cleaner and more efficient fossil fuel technology.

In the short and medium term each concept of SD will surely produce higher costs in energy supply relative to strategies focusing on an excessive use of natural resources such as fossil fuels. In many cases LDCs might not be able or willing to bear these up-front costs.

The next section gives an overview of the necessary economic preconditions and the measures which may be taken for a successful implementation of the leap-frogging concept.

### 3. Economic Preconditions for Leap-Frogging

### 3. Conditions économiques requises en matière de Leap-Frogging

The poor energy efficiency performance in LDCs and former Centrally Planned Economies is only partly due to technological reasons, but rather to issues related to the economic framework. An operational directory regarding these reasons is given by the World Bank (Energy Efficiency, 1993). The main items stated in this study are low energy prices, protected industries, public monopolies and a bias against efficiency in financing within the market structure for energy use. Further on, there are public monopolies, command and control regulations and opaque accountability regarding energy supply-side institutions. Moreover, there are deficiencies in the intermediation of information, technology and finance.

An improvement in these areas requires the increase of productivity and efficiency in the sense that the value-added can be increased with a given input of capital, work force, energy and environmental goods. In most cases, a reduction of energy intensity leads to higher capital costs, since energy efficiency follows a substitution of energy for capital.

This shows that technical progress depends on the relative prices for energy and the costs of environmental damages relative to capital costs. Thus, the higher the prices of energy or other environmental assets and the lower the cost of capital for the energy sector the higher is the potential for „leap-frogging“.

In this respect, the political discussion has been focused on increasing energy prices through taxation of energy and CO<sub>2</sub>-emissions. However, this discussion neglects two major points:

- In most industrialized countries prices of energy range substantially above world market prices because of taxes on energy. A further increase of taxation in these countries would not cause substantial increases in energy efficiency.
- High differences in energy taxes between countries lead to a concentration of energy-intensive industries in those parts of the world, where energy prices are low and thus not urging towards a leap-frog strategy. This holds especially true for those countries maintaining price regulations that result in energy price levels lower than the world market price. Thus, the problem with leap-frogging is not higher taxes on energy, but rather removing underpricing in some economies.

A World Bank Study (Larsen and Shah, 1992) shows that the elimination of all subsidies on fossil fuels leading to the underpricing of energy in LDCs and Countries in Transition amounted to \$ 230 billion in 1992 <sup>1)</sup>. A price liberalization would set free financial resources for investments in efficient and clean energy technology.

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1) Particularly in the Former Soviet Union energy prices were less than 10% of the world market prices, while in Poland, Czech Republic, China, Egypt, Ecuador, Peru, Argentina and Venezuela energy prices are solely half of the latter price. More than half of the direct and indirect subsidies were allocated to oil products. Front-runner in giving subsidies was the Commonwealth of Independent States (CIS) with \$ 172 billion, followed by China (\$ 14 billion), Poland (\$ 9 billion), Czech Republic, Brazil, Venezuela, Mexico, India and Indonesia (each of them with \$ 3 billion).



Moreover, Shah and Larsen also analyzed the environmental effects of a structural adjustment induced by liberalization of energy prices in these countries. Accordingly, these structural adjustments would result in a reduction of global CO<sub>2</sub>-emissions by 5 % over the 1990 level. In order to reach the same effect in industrialized countries, a CO<sub>2</sub>-tax of \$ 60 - 70 would have to be implemented. However, this measure would come at the cost of a world GDP decline. By contrast, structural adjustment programs, such as price liberalization, contribute to the increase of output especially in the respective countries.<sup>1)</sup>

However, price liberalization calls for temporary support measures like social transfers to compensate structural changes in personnel income-distribution and to compensate for the impacts on competitiveness of energy-intensive companies. Since changes in energy prices lead to substantial changes in economic structure and distribution of income, assistance is needed. Support has to be granted both on the bilateral basis as well as by international organizations (e. g. World Bank, IMF). On the multilateral level, the Global Environmental Facility could be used to support the adjustment process in the energy sector by supporting the substitution of energy-intensive and highly polluting production capacities.

Nevertheless, price liberalisation is a necessary but not sufficient condition for successful leap-frogging strategies. As it has been discussed above, jumps in energy efficiency require both higher prices of energy reflecting the natural scarcity and a supply of cheap capital to ease the substitution of energy for capital in the production processes. A stop of underpricing practices will most likely not release enough capital to facilitate this jump. Thus, additional capital has to be found by allocating capital to those countries and those sectors, in which the highest increase of energy efficiency per \$ of investment can be achieved.

This requires appropriate measures in industrialized countries in the sense that all countries aiming at a reduction of CO<sub>2</sub>-emissions could allow their industries to choose between investment in their own country and abroad, as long as the investment abroad yields at least the same increase in energy efficiency. Such options could be installed in various forms:

- In countries which have implemented a tax on energy or CO<sub>2</sub> for energy and environmental policy reasons one can think of a refund system for the payers undertaking investments in energy efficiency abroad.
- Other countries may aim at a CO<sub>2</sub>-reduction-goal which is to be achieved by a bundle of policy measures. A part of such a bundle could be an agreement between government and industry on CO<sub>2</sub>-reduction and increases in energy efficiency. Such agreements would have to include an option for foreign direct investments in energy efficiency, which would have to be treated equally as domestic investments.

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1) The elimination of all direct and indirect subsidies, which are responsible for high economic cost, must even be in the interest of LDCs and Countries in Transition, since the GDP will grow. Referring to Larsen and Shah the rise in GDP would amount to \$ 22 billion in the CIS, whereas in Czech/Slovak Republic, India, Poland and Brazil to more than \$ 2 billion each.



Such arrangements can help to institutionalize a global capital market for investment in energy efficiency, as firms in industrialized countries would be given an incentive to search for investment opportunities abroad and to evaluate them. As an international arrangement on the global reduction of CO<sub>2</sub>-emissions, e. g., specific quotas for individual countries, are out of reach in the near future, a privately organized capital market could be the first step towards leap-frogging-strategy.

However, foreign direct investment is also dependent on market structure and system reforms. Leap-Frogging will be quite easier and much more effective if energy markets are competitive and the intervention of government with respect to the operation of electricity utilities are low profile. The privatization within the electricity sector is already on its way in some Asian countries (i. e. the Philippines, Malaysia, Thailand, Indonesia). <sup>1)</sup>

#### **4. Technical Potential for Leap-Frogging with Special Reference to Coal**

#### **4. Potentiel technique relatif au Leap-Frogging avec référence spéciale au charbon**

Since coal is one of the fastest growing energy sources in the developing world, clean coal technology and its implementation in LDCs and NICs deserves special attention. This requires a continued usage of coal and respective research & development (R & D) activities in industrialized countries. Other suitable means in achieving SD are the installation of renewable energy systems, decentralisation of energy supply, better-aimed education and vocational training.

Since the availability of indigenous energy resources, energy needs and the geographical situation may differ across countries, there is not a standard energy system that will make leap-frogging work. Moreover, determination on an appropriate leap-frogging strategy depends on a country's developmental stage. Many developing nations have followed the original approach of the USA or that of the USSR and have built up centralized and interconnected power systems, even though the connection of remote and less industrialized areas is all but economical given the present technological options. However, once there is a centralized power system, it makes no sense both in economic and in environmental terms to switch over to a decentralized system. Especially in those cases, a very determined development of coal technologies is needed in order to dampen the upward slope of coal demand for power production. Following the scenarios of the IEA (1994), the respective coal demand will increase by an average of 3 % annually until 2020. The question whether this electricity demand can be managed in a sustainable way requires the fostering of clean coal technologies, as there is no alternative fuel that can replace coal in electricity production in the long-run.

However, in regions which are not connected to a national grid, investment in decentralized systems using renewable energy sources is a more appropriate solution. In these cases, the higher costs of renewable energy production usually range below the cost of connection to the national grid. Moreover, the connection of remote villages to the national grid involves high transformation losses leading to an energy intensive electricity production and a low energy efficiency.

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1) Further information regarding the privatization process in developing countries is given by Wiesengart (1994) It has to be noted that in some developing countries institutional arrangements are characterized by a lack of skilled workforces, overloaded facilities, very low base wages as well as inadequate legislation and government policies which are in many cases counterproductive (Abaza, 1993, page 8).

Hence, one has also to take into consideration that renewable energy sources, even though not cost efficient in general, may become competitive when used in rural and remote areas in LDCs. In many cases, it is conducive for economic and environmental reasons to install solar-energy-systems together with energy-storage-systems, i. e. batteries for small remote villages, than to install a diesel generator (Dienhart, Helmut; Georg Hille, 1994). The same does also apply to small hydro-power-stations.

**a) *Leap-frogging through clean fossil fuel technologies***

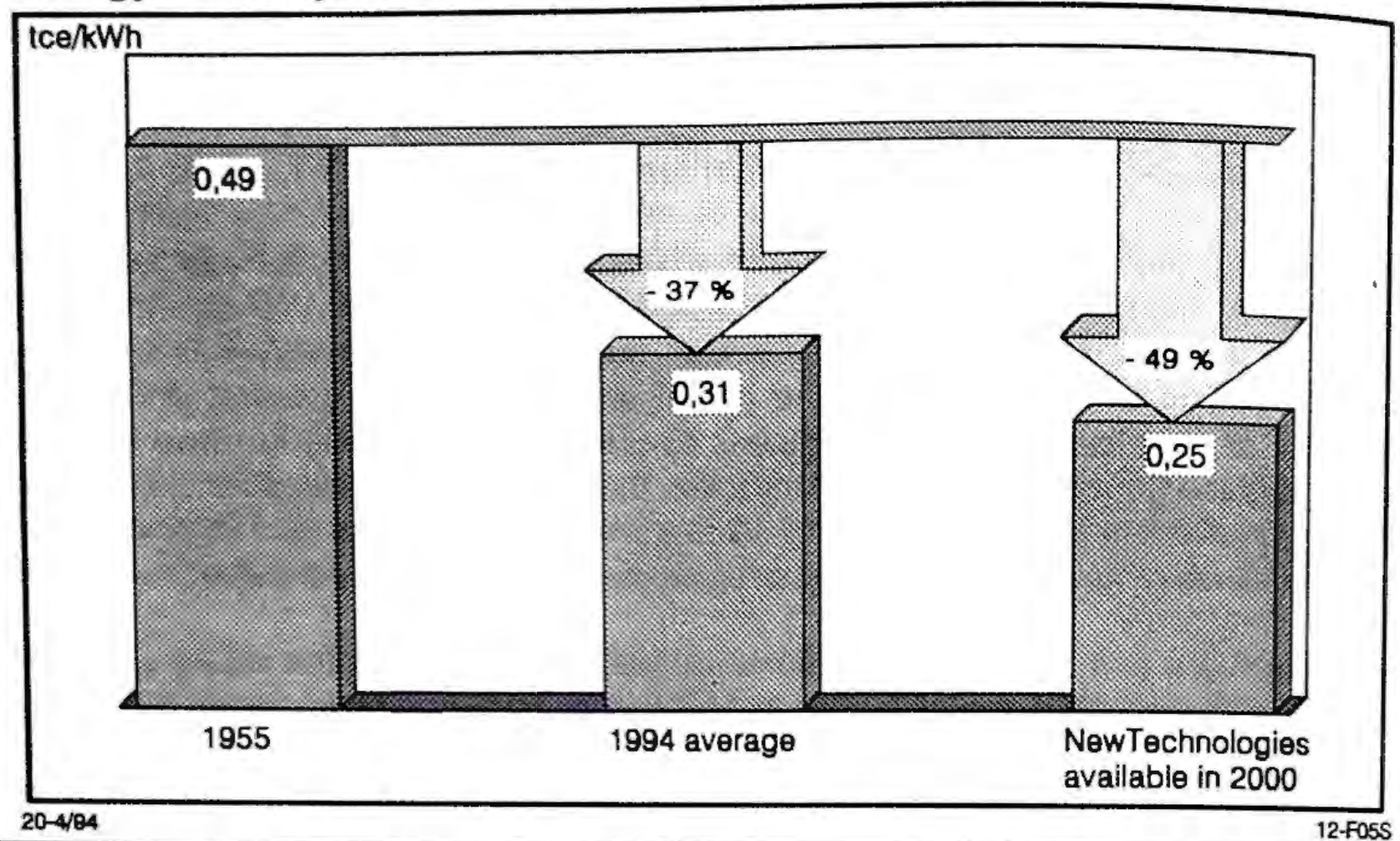
To meet the growing energy demand in the Third World, Eastern Europe and in the former Soviet Union, i. e. in all former centrally planned economies (CPEs), the use of fossil fuels is inevitable, even considering that renewable energy resources will dramatically increase their share in the global energy mix. The growing demand will particularly be met by coal, which continues to play a dominant role in these countries and to a lesser extent by natural gas. A problem that has to be mentioned in this context, is the very low efficiency of coal use in these countries, which leads to a higher demand of fossil fuels accompanied by environmental damages, mainly air and water pollution.

Since coal is one of the most important energy fuels for the future, the following chapter will deal particularly with the use of coal and the availability of clean coal technology which is already used in the most OECD countries and could be transferred to LDCs and former CPEs even in the short run. The world coal demand in 1993 (BP, 1994) amounted to 2141.1 Mtoe, of which 882.3 Mtoe or 41 % were consumed in Asia-Pacific region. The two major coal consumers in this region are China (541.5 Mtoe) and India (117.0 Mtoe). Thus, the Asian share of world coal demand is quite high and several forecasts show that this share will still grow in the coming years.

Therefore, it is quite important to use efficient clean coal technology to minimize the consumption of coal and the respective environmental impacts. Compared to efficiency levels of 40 % in OECD countries, efficiencies of about 30 % in the developing world are very low. The most efficient technologies being used today or to be used in the near future are the Circulating Fluidised Bed Combustion (CFBC), the Pulverised Fluidised Combustion Systems (PFBC), the Integrated Gasification Combined Cycle (IGCC) and Topping Cycles (developed by British Coal, VEW, Foster Wheeler and Lurgi) for power generation. All these technologies can increase energy efficiency in coal-fired power plants by another 10 percentage points (see figure 4). In the same vein, lignite-fired power plants using IGCC can reach efficiency levels of 45 %. The respective technology, which has been developed by STEAG AG, a subsidiary of the RAG Group, is also suited for small-scale plants reaching 50 - 150 MW.



**Figure 4:**  
**Energy Intensity in Coal-fired Power Plants in Germany**



Furthermore, cogeneration of heat and electricity can boost the level of efficiency to 80 % of the energy input. The latter does not require a jump in technologies but rather efforts in environmentally sound energy planning. For industrial heat processes, there are technologies available like Stocker Firing and Fluidized Bed Combustion (FBC). Moreover, several technologies have been developed for domestic coal use e. g. the Smokeless Fuel Manufacture should be mentioned <sup>1)</sup>.

Similarly, there exist „greening“ processes for coking plants. Apart from the growing efficiency in coke input in the steel industry, a reduction of coking plant emissions by more than 50 % can be achieved through replacing old plants (see figure 5). This was the experience of the RAG-Group which substituted two smaller plants for one larger plant of equal capacity but unprecedented environmental standards.

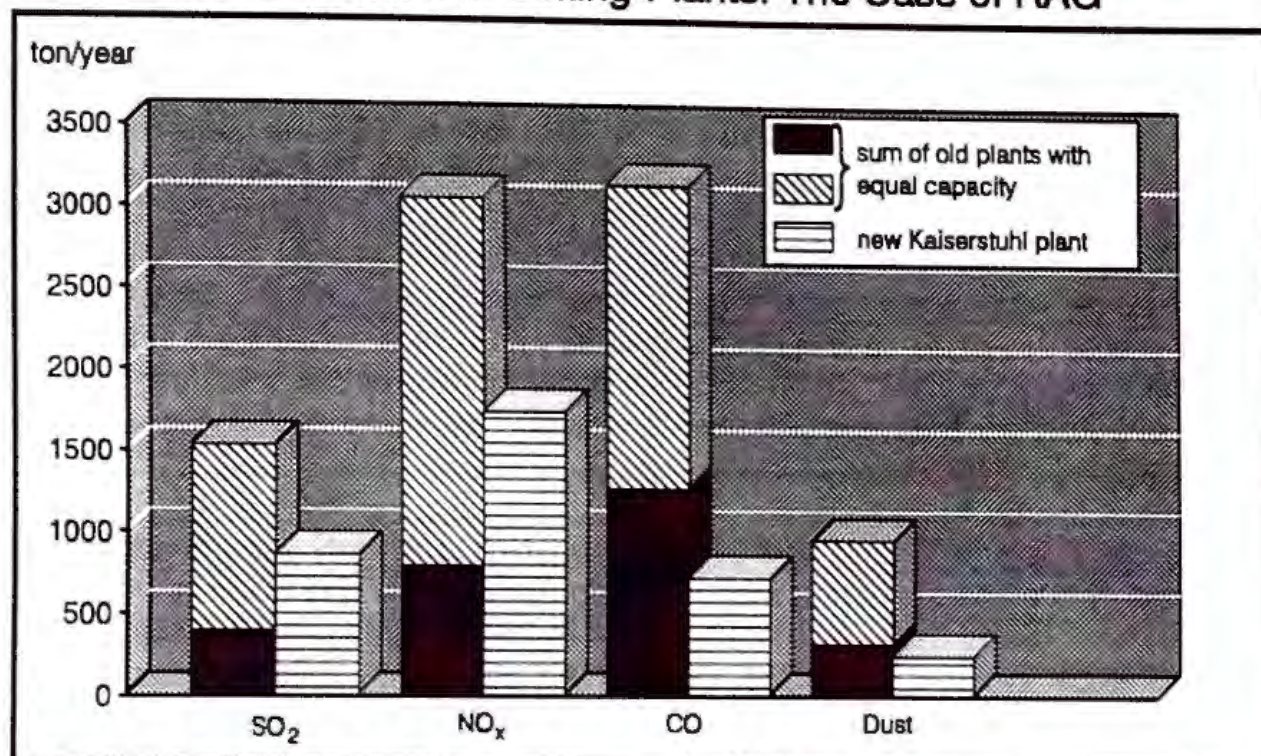
1) A broader description regarding technological items of these technologies is given by Topper (1993).



Figure 5:

# Reduction in Emissions of Coking-Plants: The Case of RAG

RAG



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All these technologies bear a high potential for solving global environmental issues. This does especially apply to the risks associated with the greenhouse effect. A jump in the efficiency of coal-fired power plants in the sense that the global average equals the level of OECD-countries could reduce worldwide CO<sub>2</sub>-emissions by 5 %. Investments in replacing old coal-fired power plants in LDCs and in former CPEs are much more efficient than replacing capacities in OECD countries, as the following example shows.

The efficiency of coal-fired power plants in the CIS averaged 25% in 1991. More than 210 Mtce of hard and brown coal had been used in power stations, while the respective CO<sub>2</sub>-emissions amounted to 570 Mt per year. An increase to an efficiency of 38 % would lead to a reduction in CO<sub>2</sub>-emissions of about 190 Mt to 380 Mt. This alone accounts for 1 % of the total world-wide CO<sub>2</sub> and about 5 % of the CO<sub>2</sub> emitted by the CIS (Amelung, Laufer, 1992). To gain this reduction in CO<sub>2</sub> emissions a replacement of the old coal fired power station facilities through new ones with higher efficiency levels is necessary. The costs for such an investment program total approximately 118 billion DM. This sum is only one third of the financial needs of the German CO<sub>2</sub>-reduction program which until 2005 is supposed to result in an equal reduction of CO<sub>2</sub>-emissions. However, investment in new power plants is inhibited through the desperate financial situation in many countries so that they have to postpone the necessary investments. The result is that inefficient units keep producing electricity. Thus, to foster a replacement of all these plants soft loans have to be given, while the replacement has to be a part of the conditionality.



## ***b) The Economic Potential of Renewable Energy Sources***

Moreover, renewable energy sources yield an additional potential:

- **Traditional fuels** like firewood, charcoal, animal waste and crops residues, in the following referred to as biomass, has been playing a dominant role in the energy sector of the Third World. Yet the use of biomass in most LDCs is quite unorganized, while few countries like for instance China, Malaysia, the Philippines and Thailand use biomass very extensively. The two latter countries use biomass predominantly in their industrial sector. Indonesia meets about 60 % of its energy demand of cottage industries by the use of charcoal and firewood (Imran, 1993, p 42). Though basically the energetic use of biomass is not detrimental with respect to the greenhouse effect, inefficient use of biomass, deforestation and the farming of crops for fuel production may have serious negative environmental impacts that may outweigh the advantages of these traditional fuels.
- **Hydro power** is a renewable energy resource which is already used in a large scale for world-wide electricity production. Following Schwengels and Solomon (1992) only 5 % to 10 % of the hydroelectric potential has been developed in Africa, Asia and Latin America. Whether large-scale hydro power generation is competitive compared to fossil fuel-fired plants depends on whether or not it is possible to enter the hydro based electricity into the existing grid or to connect it direct to users on competitive costs (Foell, K. Wesley; Mark E. Hanson and Collins W. Green 1993, pp 41). Therefore, in remote areas that are not linked to the national grid small hydropower stations are less costly.
- **Solar energy** is still the most expensive renewable energy source. However, the World Bank (1992, p 123) states that in the next decade the use of solar energy for electricity production could become competitive with nuclear power in areas with major solar insolation intensities and in the long-run perhaps also with fossil fuels. There are different technologies available to use direct solar energy. Competitive for domestic use by contrast, photovoltaic systems are still restricted to remote rural areas for which a connection to the national grid requires high investment costs (Foell, K. Wesley; Mark E. Hanson; Collin W. Green, 1993, pp. 40). The production of solar collectors is quite energy intensive, so that fostering the use of solar energy would initially lead to a higher use of fossil fuels.
- The theoretical **geothermal energy** resource potential world wide is very large. The resources can be divided into three different groups. The most important one is the hydrothermal, followed by the hot-dry-rock and geo-pressured resources. Today only the first resource is being exploited. Countries with a very large potential in Asia for example are China, Indonesia and the Philippines (Schwengels, Paul F.; Barry D. Solomon, pp 44).
- Most of today's existing **wind energy** projects are located in OECD-countries and in California and only to a lower extent in LDCs i. e. China, Egypt and Sri Lanka. The following description about the situation in Sri Lanka is a short summary of an overview about the potential of wind energy in Sri Lanka given by Meier, Peter and Mohan Munasinghe. However, wind power is primarily used in agricultural sector, to operate pumps for small scale irrigation. If this potential is used it could be possible to displace smaller fossil fuel power plants and decentralized systems depending on fossil fuels.



Except for large-scale hydropower there is no question that these technologies perform well both in economic and environmental terms when used in decentralized systems. However, only large-scale hydropower plants are in a position to serve as a supplier of industrial energy needs because of the high costs of small-scale renewables. Even the latest technologies cannot keep up with conventional energy sources as can be obtained from the following table featuring the costs of renewables in Germany.

<b>Table 1: Costs of Electricity Production in Germany by various Fuels using latest Technologies</b>	
Energy Source	Costs (DM per kWh)
Wind energy	0.15 - 0.30
Small-scale hydropower	0.25 - 0.30
Large-scale hydropower	0.04
Photovoltaic energy	2.00 - 2.50
Nuclear power	0.13
Coal (combined-cycle power plant)	0.14
Source: Schiffer (1994)	

This shows that a large scale application of renewables for replacing fossil fuels and leap-frogging is out of reach because this process involves extremely high amounts of capital. Thus, in most cases an investment in conventional technologies is a more efficient alternative both in terms of economic and environmental aspects.

- The costs of photovoltaic technologies amount to 22,000 DM per kW of capacity. Assuming that this technology is to replace a conventional coal-fired plant, the costs of CO<sub>2</sub>-abatement adds up to 220 DM per kW capacity for 1 % decline in CO<sub>2</sub>-emissions.
- A combined-cycle coal-fired power plant reaching an efficiency of 40 % requires an investment of 2,500 DM per kW of capacity. Assuming that such a power plant replaces an old coal-fired plant with an efficiency of 30 %, the costs of a 1 % CO<sub>2</sub>-abatement averages 160 DM per kW capacity.

This lends support to the hypothesis that given the present technologies leap-frogging has to be achieved through investment in conventional power systems.

## 5. Summary and Conclusion

### 5. Résumé et conclusions

The implementation of SD strategies in the energy sector requires adjustments in all countries regardless of their developmental stages. Because of the scarcity of environmental and natural resources developing countries can hardly follow the growth path of industrialized countries which was fostered by an excessive growth in fossil fuel consumption. Hence, sustainability calls for a jump in energy efficiency which is known as a leap-frogging strategy. Such a strategy, however, has to take account of the energy needs of developing countries which face a high growth of coal and electricity consumption. For reasons of resource endowment, coal is expected to gain importance

in the global energy mix. This points to the fact that higher efficiency levels have to be achieved especially through the use of new technologies. In addition, renewable energy sources have to increase their market shares in those regions that are not connected to a national grid. Usually, the high costs of these resources are more than outweighed by investments in interconnected systems. However, in regions with an existing interconnected grid, investment in coal technologies is more efficient both in economic and environmental terms, as the paper shows.

Achieving higher efficiency levels involves a substitution of energy for capital, which has to be raised to fuel the substitution process. Part of these financial resources can be freed, if countries stop the underpricing of energy, thus realizing savings in direct and indirect subsidies. Moreover, financial resources in industrialized countries have to be directed to developing countries. Given the low level of energy efficiency of the energy sector in most non-OECD countries an efficient and effective use of scarce financial resources calls for an internationalization of the respective capital flows.

A first step could be institutionalized in such a way that measures of CO<sub>2</sub>-abatement in industrialized countries allow their industries to realize efficiency increases beyond their national borders, while these efforts should be treated equally as commitments for national CO<sub>2</sub>-abatement. Though such a system should be regarded as a tentative though highly effective first step, it does not require the enforcement of a global treaty on CO<sub>2</sub>-abatement, which can hardly be achieved given the present conflicts of interests between individual countries.



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