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# The Climate Change and the Power Industry

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## 1. Introduction

Electricity generation is responsible to a large extent for the climate change all over the world. To reach the sustainable power supply the RENewable ratio should be raised and the $CO_2$ emission technologies should be rolled back. The indirect cost of the climate changes appearing later, the harmful effects and the irreversible environment change are expressed by the externality cost. This paper shows a linear programming optimization technique how one can define the optimal portfolio having clear data and targets. The key of the problem is to find approved initial data and objectives accepted by the society that we want to reach. In practice there are dozens of real and lobby tasks, so it is really hard to judge what is the multi-compound-objective function what we optimize for.

We introduce the trends of energy needs and emission and the basic power generation technologies. We define the notion of externalities and power mix. A method is shown how the ideal generation mix can be defined by linear programming tools. The result shows that the renewable sources mean cheap solution for long term. We show the different ways how to decrease the $CO_2$ emission of the power technologies. These are the decrease of the amount of the used electricity; changing the generation portfolio; raising the electrical efficiency of the generation and trapping the exhausted $CO_2$. Finally we discuss the difficulties of the decision making regarding the power plant constructions.

## 2. GHG and the energy industry

The green house gases (GHG) create a special heat trap around the Earth globe and this phenomenon is considered one of the causes of the global climate change, the raise of the yearly average temperature. There are many GHGs, the two most important are the $CO_2$ and methane. Although at each technology the structure and ratio of the emission could be measured or counted, the $CO_2$ emission is the most simple and characteristic component that is why it is used as indicator of the mischievousness of a technology. The direct $CO_2$ emission origins from the combustion technology of the fossil fuel (oil, gas or coal) the indirect $CO_2$ production must be taking into account what is produced during the whole life cycle of the power plant construction and decommissioning and also during mining and processing the fuel.

In spite of all the efforts of the global $CO_2$ emission, the exertion of the fossil materials increases sharply. The exploited primary energy sources after some delay are transformed into $CO_2$. The main emitters are the power, metal, construction and transportation industries (see fig.1.).
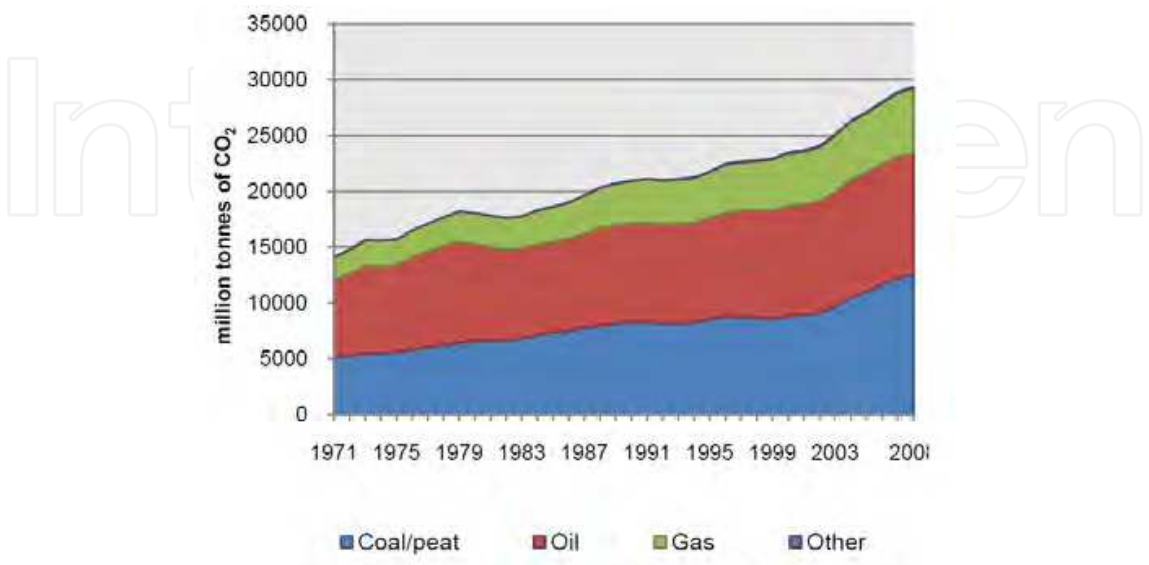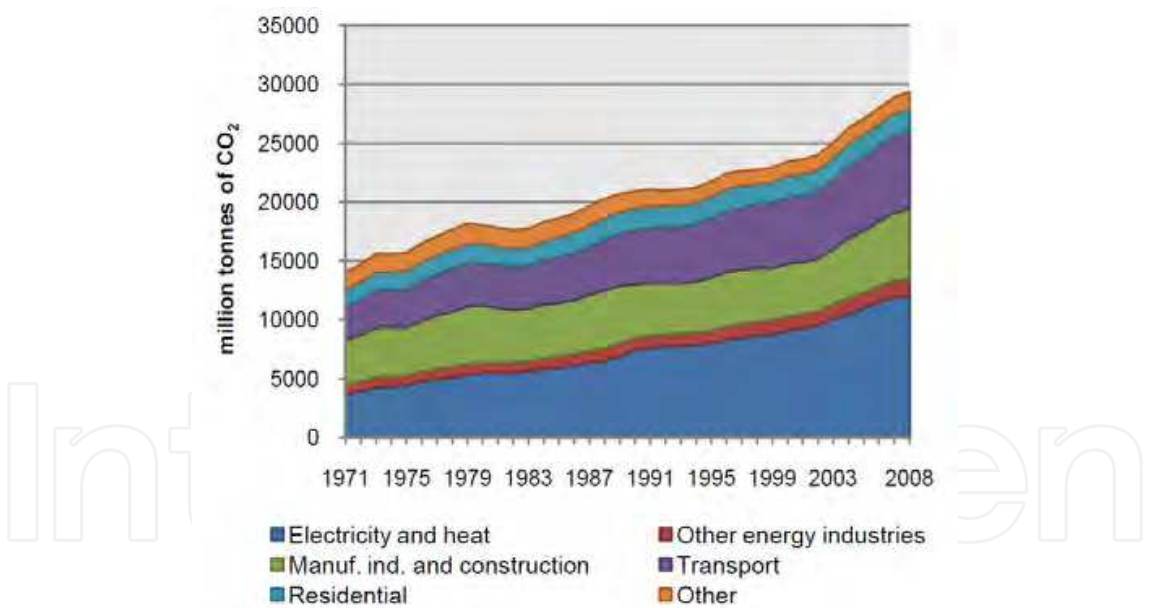


Fig. 1. $CO_2$ emission by fossil fuels[1]



Fig. 2. $CO_2$ emission by sector[1]

As one can see the power sector (electricity and heat) is responsible for more than one third of the total $CO_2$ emission (see fig.2.). If we look for the primary source of the electricity generation, we can see that almost 60 % is fossil fuel (see fig.3.). Having known this fact it is hard to fight against the $CO_2$ emission.

[1] $CO_2$ Emissions from fuel combustion *Highlights* (2010 Edition);
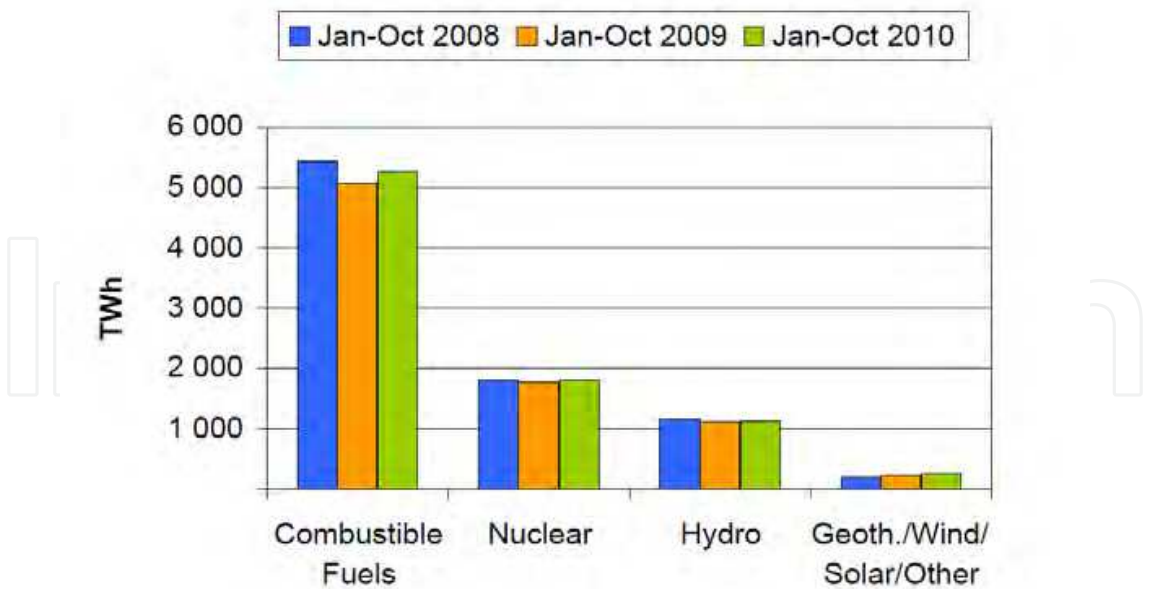http://www.iea.org/co2highlights/co2highlights.pdf

Fig. 3. Monthly worldwide electrical energy generation by primary sources[2]

This global ratio differs in certain countries. E.g. in Hungary is only 0,5% the hydro and 4% the other renewable generation for the lack of these type of sources and plants (see fig.4.).
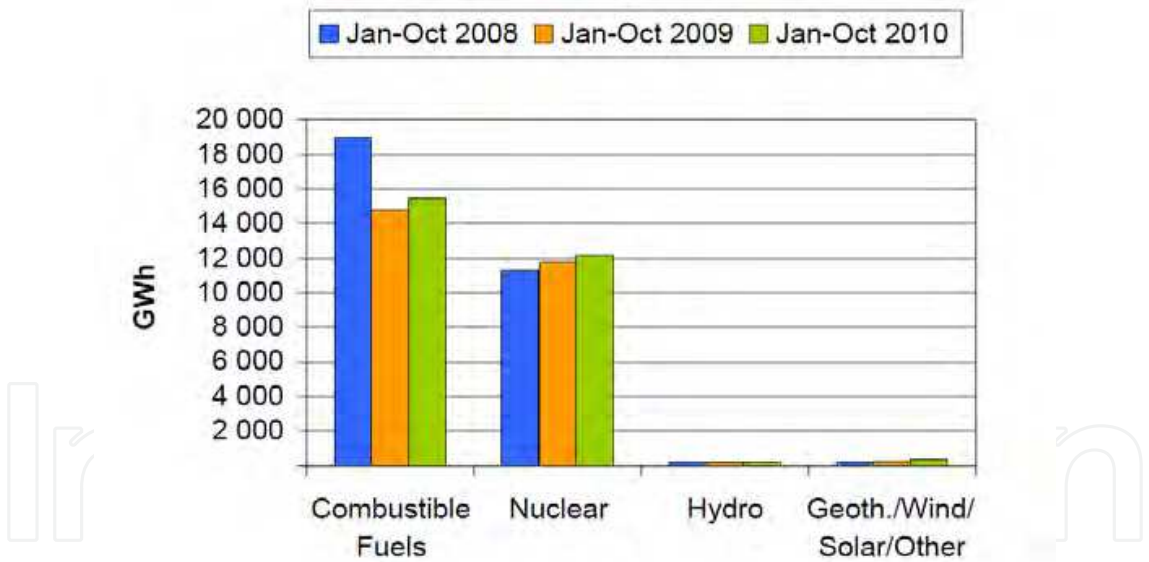


Fig. 4. Monthly electrical energy generation by primary sources in Hungary[2]

More frightening is that the emission growth of the electricity industry is among the highest (is not kept on a level or decreases – see fig.5.). The global growths of the emission and the high fossil ratio seem to be constant in spite of $CO_2$ reduction efforts, directives and conferences. And the energy starve do not stops in the near future (see fig.6.).

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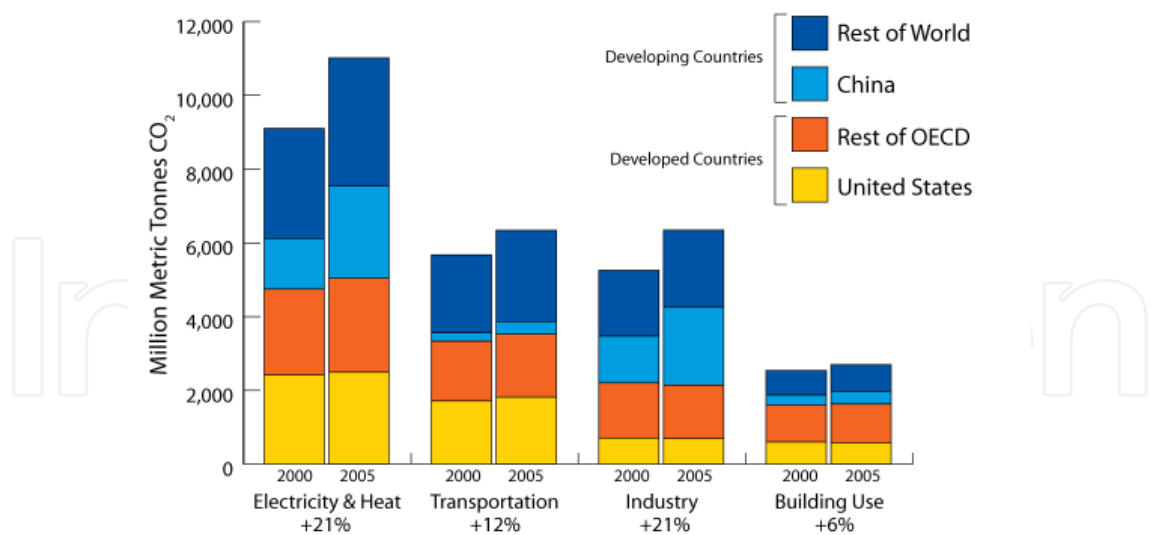[2] Monthly Electricity Statistics November 2010; 'Year to Date' Comparison of Production by Fuel Type; http://www.iea.org/stats/surveys/mes.pdf

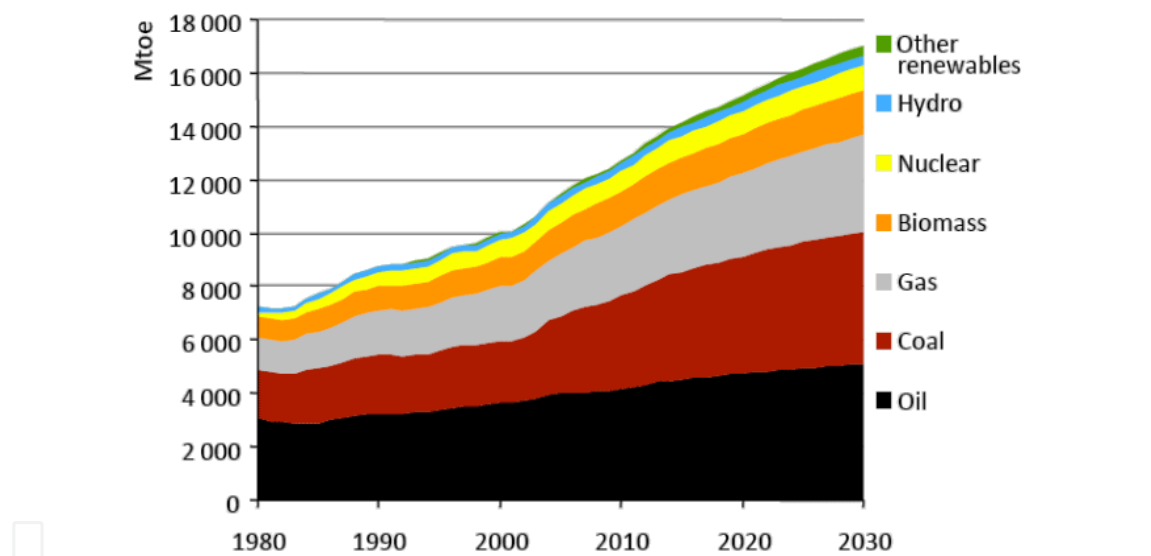Fig. 5. Global $CO_2$ emission growth in selected sectors 2000-2005[3]



Fig. 6. Primary energy need outlook till 2030[4]

## 3. Basic power generation technologies

In this subchapter the traditional and renewable power (heat and electricity) generation technologies, their operation, measures and effects are enumerated.

In the industrialized world the primary energy sources (coal, oil, natural gas) are transformed into secondary energy forms, such as heat and electricity, that can be easily handled at end-user technology. This transformation is performed in power plants. Figure 7. shows this general transformation scheme.
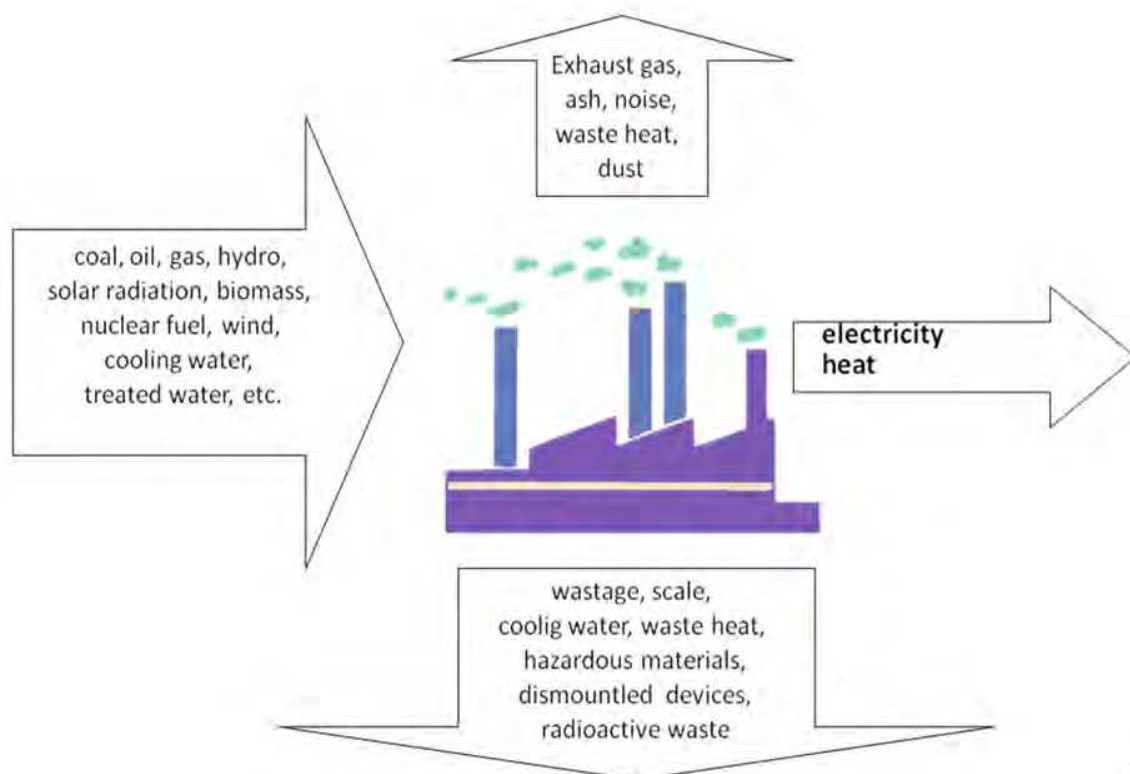
[3] http://www.usablemarkets.com/2010/06/13/world-greenhouse-gas-emissions
[4] http://www.energy4me.org/energy-facts/energy-sustainability

Fig. 7. Energy transformation in power plant

### 3.1 Coal fired power plant

Up to the middle of the 20th century the coal fired plants had hegemony. It has a new renaissance typically in China.

The powdered coal boils the treated water into steam in furnaces. The steam turbines run generators. The dead steam is condensed into liquid form by condenser in cooling towers (or other cooler solution).

- Fuel: coal (from the stone coal to the lignite)
- Typical electrical efficiency: 30 – 45%
- Measure: 200 – 800 MW/ unit; 1000 – 2000 MW/ plant

### 3.2 Oil/gas fired power plant

The strong development of oil based plants dates back to the middle of the 20th century. The technology is relatively simple and clean, no special solid rest or refuse handling technology is required. The power output of these plants can be controlled in wide range between 30-100%.

In the traditional technology the gas or oil boils the treated water into steam in furnaces. The steam turbines run generators. The dead steam is condensed in liquid form by condenser in cooling towers.

- Fuel: wide variety of oil and gas
- Typical electrical efficiency: 30 – 45%
- Measure, bulk plant: 200 – 400 MW/ unit; 1000 – 2000 MW/ plant

The gas turbine technology origins from the aircraft engine industry. The machine has three sections:

- a compressor section for the raise of the temperature and pressure of the air
- a second stage, where fuel (natural gas or oil vapour) is burning producing high pressure and temperature exhaust gas.
- the third section (in case of heavy duty power generation turbines), where a turbine is driven by the exhaust gas providing torque for electric generator.

The gas turbines work by open Carnot-cycle, the hot and expanded burned oil or gas (exhaust gas) turns directly the turbine.

- Fuel: fuel oil or gas
- Typical electrical efficiency: 45 - 60%
- Measure, bulk plant: 130 – 250 MW/ unit; 400- 1000 MW/ plant

### 3.3 Nuclear power plant

The nuclear plants are based on radioactive fission. These plants produce relatively cheap bulk base energy in spite of the high investment cost. There are more than 400 units in operation all over the world.

The fission produces heat in the fuel cassettes and this is cooled by water that turns into steam in the Boiled Water Reactor (BWR). The steam turbines run generators. The dead steam is condensed in liquid form by condenser. In the Pressurized Water Reactor (PWR) in the primary circle the water do not boils, the heat transferred through heat exchanger into the secondary, boiled water circle. The nuclear fission has no direct $CO_2$ emission. The construction process, the steel and cement production and fuel processing have remarkable emission. Eventually there is unwanted radioactive emission.

- Fuel: enriched uranium
- Typical electrical efficiency: 30 %
- Measure: 300 – 1500 MW/ unit; 1000 – 4000 MW/ plant

### 3.4 Hydro power plant

The hydropower is one of the oldest energy technologies, e.g. it is enough to think of the watermills. The level of the natural water flow is raised by a dam, and the potential energy of the water turned into kinetic – mechanical energy. The hydro plants can have low (till 15m), medium (till 50m) and high headings. The turbines are built in the dam, in underground cave or at the end of the artificial open air channel far from the reservoir. The main turbine types are the Banki, Francis, Kaplan and Pelton. During its operation there is no $CO_2$ emission. The construction process, the cement production and the decay of the organic materials in the reservoirs have remarkable emission.

- "Fuel": water flow
- Typical electrical efficiency: 85-93 %
- Measure: 0,01 MW – 800 MW/ unit; : 0,01 MW – 20 000 MW / plant

## 4. Emissions and externalities

The energy production must be investigated in a longer time scale and in a wider context. Externality means an external economic impact that is not taken into consideration in a present transaction, e.g. in the energy generation process: now we produce cheap electricity, but no one calculates the huge future costs of the nuclear waste bury or the costs of the $CO_2$ caused climate change. These costs must be paid by the future economy, by the future

society. We talk about internalization of the externality if we assign these costs to the present transactions. In the price of the electricity over the fuel, maintenance and operation costs we should separate funds to avoid these harmful effects. The private cost is the present 'market price'. It is only a part of the total social cost (see fig.8.).
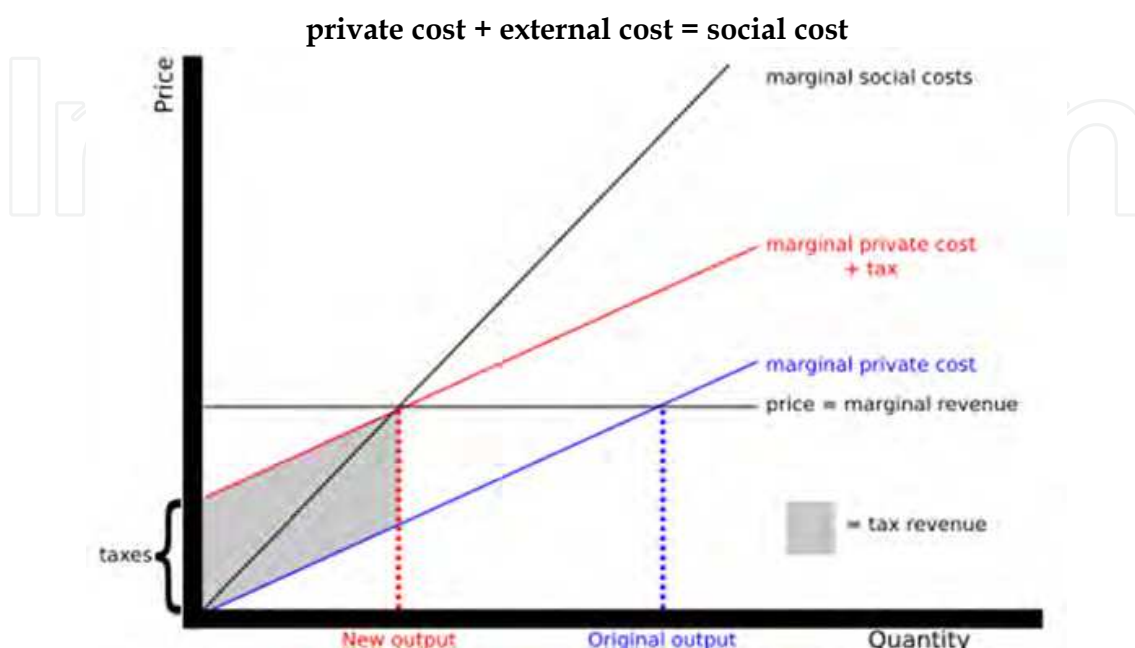


Fig. 8. The difference between the private and society costs[5]

The external cost calculation can deal with the green house gas emission, natural resource and area usage, health damage and landscape changes, too. It is a really complex process but several projects dealt with it already:
- EU ExternE project
- NEEDS consortia (New Energy Externalities Development for Sustainability)
- USA NSA project „Hidden Cost of Energy" project
- German BMU project „Externe Kosten der Stromerzeugung" project, etc.

Figure 9. shows a typical range of the externality cost that should be paid (virtually) in the future for each kWh of electricity produced and consumed today. The values depend on the investigated technology. Figure 10 refers to the Hungarian externalities.

The external cost is a greater set that contains the estimated cost of the GHG emission. Typically a greater emission technology has greater external cost but the relation is not linear. The external cost calculation is far less exact, that is why the emission measurement/calculation/estimation/trade is prevailing.

The exact external cost and the emission are valid always for a specific technology, a certain power plant. That is why the externality and emission used to given by from–to range, as an average value. This is a specific value, related to the production of 1 kWh or 1 MWh of energy. E.g. the $CO_2$ emission by coal fired plants can be approx. 700 g/kWh in case of high calorie coal and new combustion technology but it can be also 1200 g/kWh in case of lignite

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[5] United World College Mostar: Blue Books Economic Notes
http://www.scribd.com/doc/20735011/Economics-book-United-World-college-Mostar
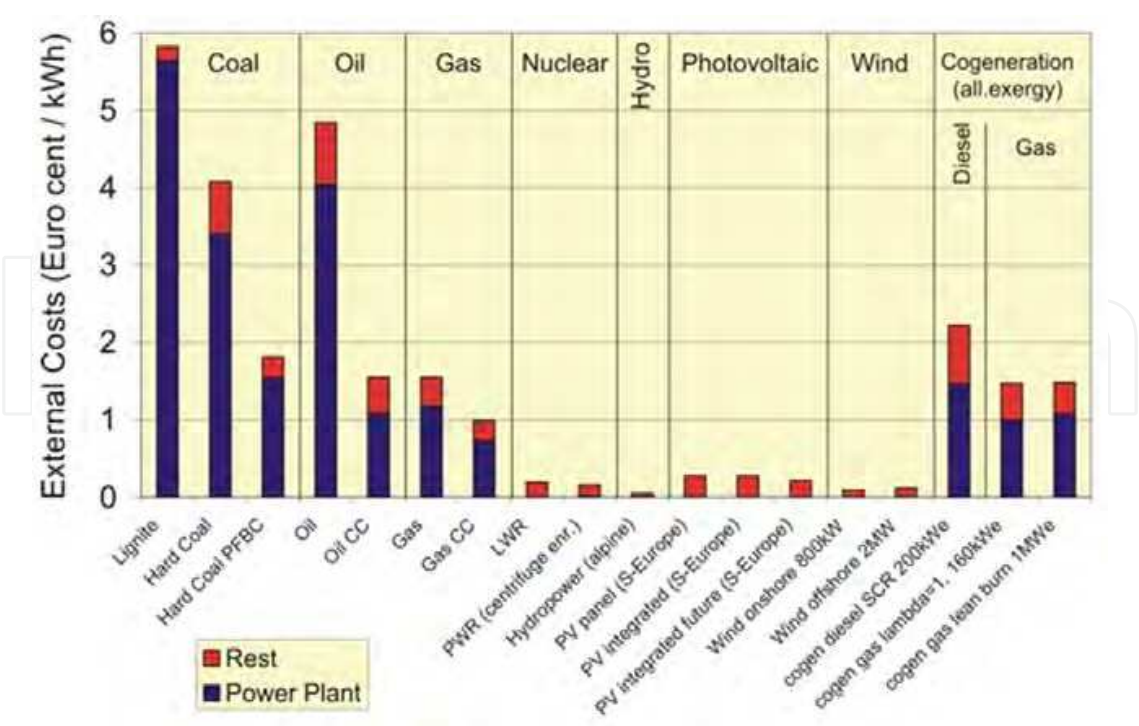
Fig. 9. External costs of current and advanced electricity systems, associated with emissions from the operation of power plant and with the rest of energy chain [6]
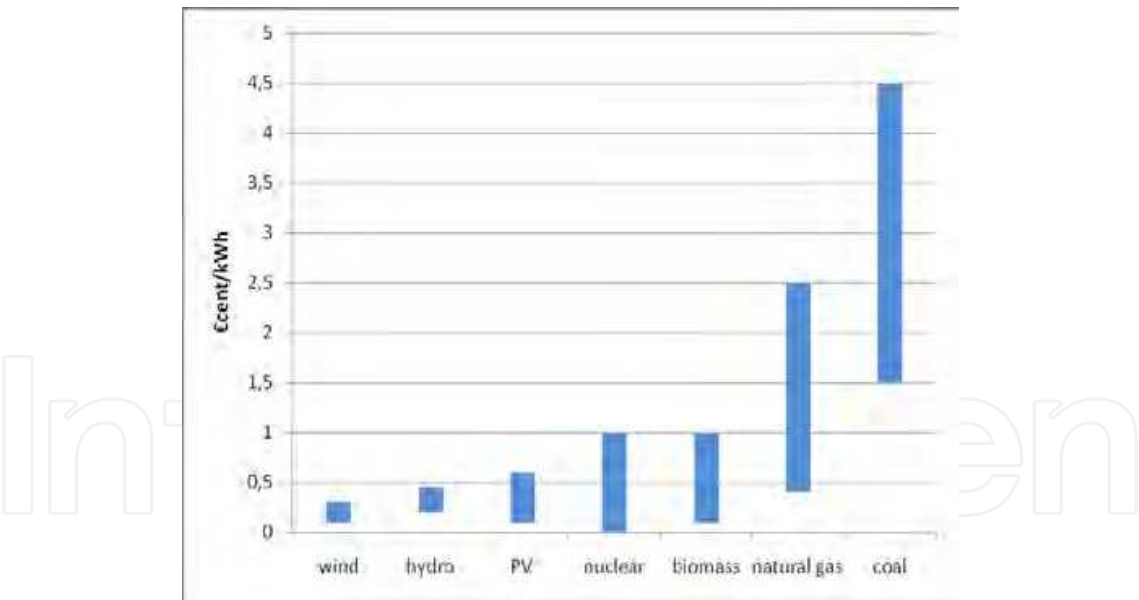


Fig. 10. External cost of electricity generation technologies in Hungary[7]

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[6] Dones R., Heck T., Bauer C., Hirschberg S., Bickel P., Preiss P., Panis L., De Vlieger I., New Energy Technologies – Final Report on Work Package 6 – Release 2, July 2005. ExternE-Pol Project 'Externalities of Energy: Extension of Accounting Framework and Policy Applications', European Commission (2005). Retrieved from http://www.externe.info/expolwp6.pdf

fired plant. Figure 11. shows these ranges, and Figure 12. shows the typical values for the Hungarian emission.
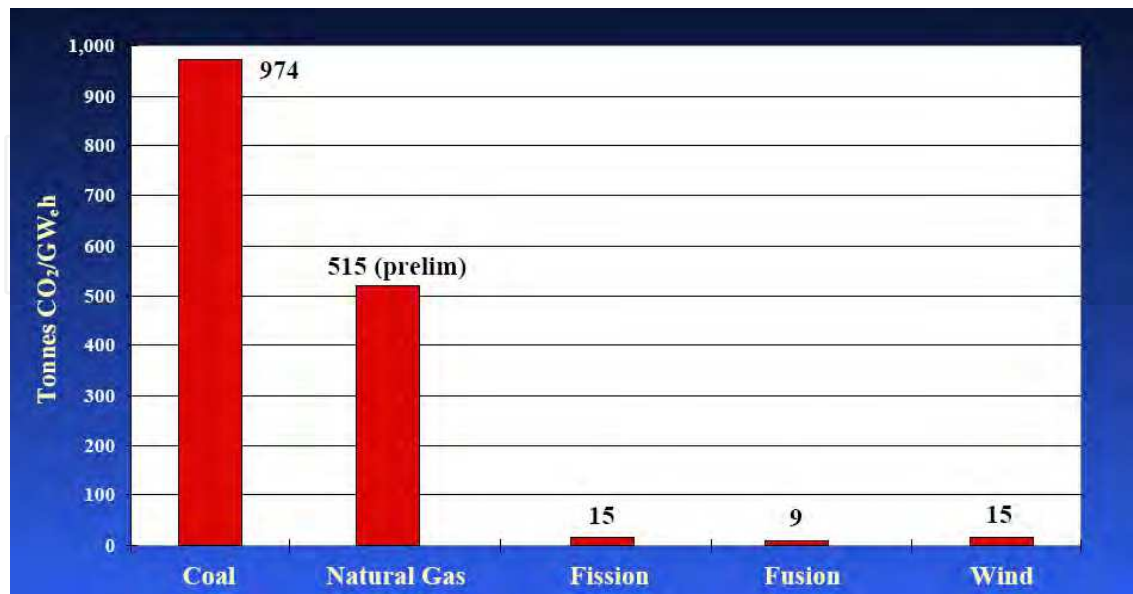


Fig. 11. A set of $CO_2$ emission data of electricity generation technologies[8]
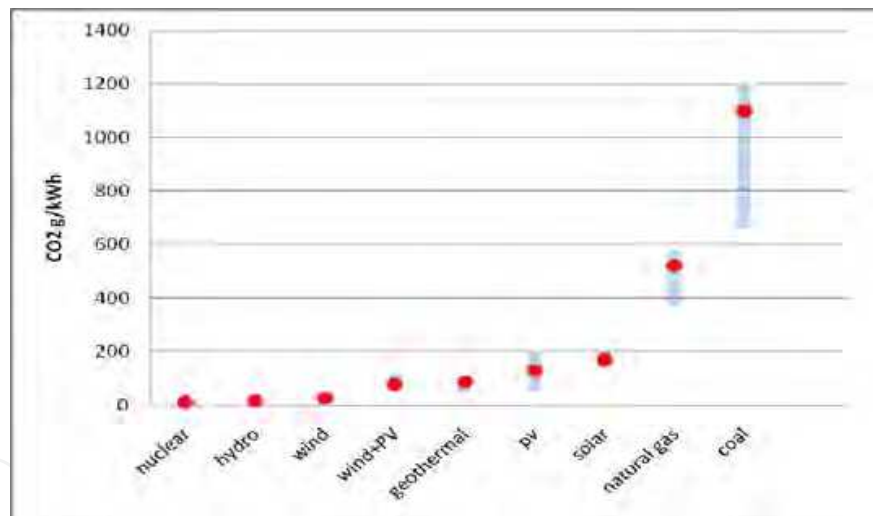


Fig. 12. $CO_2$ emission of electricity generation technologies in Hungary[7]

## 5. The ideal power mix

The country/area electric (and heat) demand is easy to forecast. This demand is fulfilled by electricity power generation in the same minutes of the need because the large electricity power is not storable in large quantity. The energy need (during the day) or the power need in a specific time is provided by a set of generators (thousands) driven by different primary

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[7] Study for the Hungarian energy Authority by the Power Consult Ltd.: The externality cost of the electricity production – special focus on the renewable sources, Budapest, 2010

[8] S.W.White – W.H.Readcliffe-G.L.Kulcinski: Life Cycle Energy Cost of Wind and Gas-Turbine Power

energy sources. The actual ratio of these sources, the actual set is named "power mix". This mix can be fully fossil - based of fully renewable, but the typical ratio is 60-70% fossil fuel, 10-30% of nuclear, 5-20% renewable (see Figure 13. – nuclear – orange, yellow – small CHP, gray – large CHP, small - brown – coal, green – gas, blue - import).
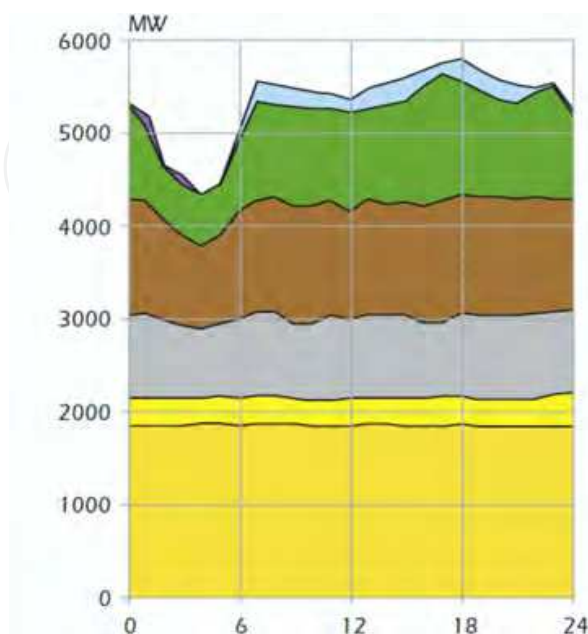


Fig. 13. Daily generation portfolio[9]

Having clear objectives on national or global level the power generation mix should be easily defined by minimizing the harmful effects. The realization is far more difficult. The European Union defined national quotes for the ratio of the renewable energy generation. For Hungary this share is 13% of the total generation for the year 2020. The current share is only 5% that is why new sources must be set up. Each technology has special requirements, effects so it is not easy to say which type must be developed, how the new renewable level should be fulfilled. The Hungarian Energy Authority started a process for the definition of the new generating capacities based on the following criteria:
- definition of the cheapest generation portfolio
- definition of the lowest $CO_2$ emission portfolio
- definition of the lowest external cost portfolio

The cheapest means that it requires the least financial effort at present but the environmental pollution is not taken into consideration (externality). The $CO_2$ emission (and other climate changing emissions) can be measured in a relatively exact way. The notion of the external cost is given above. In the following sections we introduce power generation portfolio optimization techniques:

## 5.1 Optimization

Having known that there are some cloudy targets, that should be reached by constraints and we are going to find the best solution we choose the optimization techniques (Lee & Sharkawi, 2008). There are a lot of optimization applications related to the power industry and power system, as well. (Kádár, 2009 – I, II). In simple cases we seek for Single Objective

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[9] source: MAVIR – Hungarian transmission operator

Optimum (SOO), in other cases we optimize by many aspects (Multi Objective Optimization – MOO). The energy strategy, the definition of the future energy mix is a MOO problem. Nowadays there is a large variety of numerical optimization tools. Further on we demonstrate that the above mentioned data are appropriate for the investigation of the future alternatives. In the demonstration we use SOO. The objectives are in Table 1.

| INV | Investment cost minimization |
|-----|------------------------------|
| EXT | External cost minimization |
| $CO_2$ | $CO_2$ emission minimization |

Table 1. Objectives of the optimization

| Rene wable | type | max. built in cap. | max. load factor | energy potential | energy produced/ built in MW | external cost | $CO_2$ emission |
|------------|------|--------------------|------------------|------------------|------------------------------|---------------|-----------------|
| | | MW | | TWh | TWh/MW | MEUR/TWh | Mt/TWh |
| | nuclear | 3500 | 0,95 | 29,1 | 0,008322 | 2 | 0,015 |
| | coal | 1500 | 0,75 | 9,9 | 0,00657 | 53 | 0,8 |
| | CCGT gas | 4500 | 0,8 | 31,5 | 0,007008 | 23 | 0,5 |
| R | hydro | 500 | 0,5 | 2,2 | 0,00438 | 2 | 0,015 |
| R | wind | 1500 | 0,2 | 2,6 | 0,001752 | 1 | 0,025 |
| R | biomass (central) | 500 | 0,5 | 2,2 | 0,00438 | 33 | 0,4 |
| R | PV | 200 | 0,15 | 0,3 | 0,001314 | 2,5 | 0,13 |
| R | geothermal | 100 | 0,5 | 0,4 | 0,00438 | 3 | 0,086 |
| R | biogas | 250 | 0,6 | 1,3 | 0,005256 | 3 | 0 |
| | total | | | 79,5 | | | |

Table 2. The data of the power sources

We used the following fixed data in our calculations (see Table 2).
- existing power generation capacities
- enlarging possibilities
- yearly energy demand (today 40 TWh and 50 TWh in 2020)
- load factor
- maximum energy production
- minimal energy production
- external cost/MWh
- $CO_2$ emission/MWh
- investment cost
- lifetime

Having limited primary energy sources the potential development ranges are limited:

| type | present capacities (MW) | potential enlargement in 10 years (MW) |
|---|---|---|
| nuclear | 2000 | 1500 |
| coal | 1100 | 400 |
| CCGT gas | 3500 | 1000 |
| hydro | 50 | 450 |
| wind | 300 | 1200 |
| biomass (centralized) | 300 | 200 |
| PV | 1 | 199 |
| geothermal | 5 | 95 |
| biogas | 50 | 200 |
| total | **7306** | **5244** |

Table 3. Power plant development ranges

| | investment cost for 1 year for 1 TWh (no fuel and maintenance) **MEUR/TWh** | *externalities (source NEEDS* **MEUR/TWh***)* | $CO_2 emission$ **Mt/TWh** |
|---|---|---|---|
| hydro | 3,42 | 2 | 0,015 |
| wind | 20,55 | 1 | 0,025 |
| central biomass | 5,33 | 33 | 0,4 |
| PV | 30,44 | 2,5 | 0,13 |
| geothermal | 5,71 | 3 | 0,086 |
| biogas | 6,34 | 3 | 0 |
| nuclear | 2,4 | 2 | 0,015 |
| coal | 1,83 | 53 | 0,8 |
| CCGT gas | 1,71 | 23 | 0,5 |

Table 4. Technology costs and emissions

The following SOOs were performed:
- $CO_2$ emission minimization
- $CO_2$ emission minimization, with 13% renewable share
- Externality minimization
- Externality minimization, with 13% renewable share
- Investment minimization
- Investment minimization, with 13% renewable share

The different technologies have different investment needs (power plant construction), externality cost and $CO_2$ emission. The common platform is "the cost of a power plant generating 1 TWh electricity". It is calculated from the total cost of the plant, and the total production of its life time (see Table 4.).

The objective function is a mathematical expression that shows the value of the feature to minimize. We have the followings:

> # 1 ) Investment cost minimization
> Minimize value = 3,42 (hydro) + 20,55 (wind) + 5,33 (biomass) + 30,44 (PV) +
> 5,71 (geo) + 6,34 (biogas) + 2,4 (nuc) + 1,83 (coal) + 1,71 (gas)
> # 2 ) Externality cost minimization
> Minimize value = 2 (hydro) + 1 (wind) + 33 (biomass) + 2,5 (PV) +
> 3 (geo) + 3 (biogas) + 2 (nuc) + 53 (coal) + 23 (gas)
> # 3 ) $CO_2$ emission minimization
> Minimize value = 0,015 (hydro) + 0,025 (wind) + 0,4 (biomass) + 0,13 (PV) +
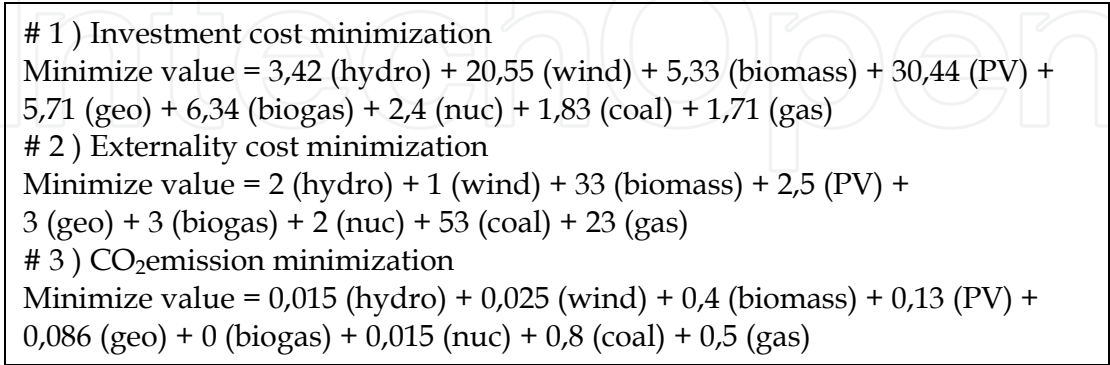> 0,086 (geo) + 0 (biogas) + 0,015 (nuc) + 0,8 (coal) + 0,5 (gas)

Fig. 14. Objective functions for minimization

All cases take into account the present existing portfolio that is we can only develop (in the green field approach we can stop any plants and we can replace that by wish).

The second step is to set up the different constraints, such as the existing minimum capacities, the possible extension ranges. After having a solution that minimizes our objective function we can calculate e.g. the total $CO_2$ load, total investment cost necessary, total operation costs. By setting up different constraint sets different alternative development scenarios can be obtained. Regarding the constraints the following limits were built in the model, related to the present situation and the physical possibilities:

- existing power generation capacities (minimum criteria)
- enlarging possibilities (maximum criteria)
- yearly energy demand (today 40 TWh and 50 TWh in 2020) - scenarios
- maximum energy production
- minimal energy production

The constraints are additional inequalities in the equation system that must be solved (see Fig.15.). First we defined an objective function to minimize. This is the total external cost coming from the individual externality of each generation type. The linear programming tool found the solution that meets all the constraints and equation furthermore it produces the minimal externality cost (see Fig 16.).

Table 5. shows the result portfolio of the externality minimization. The total generated energy is 50 TWh, the renewable ratio is 13%. The total external cost is 401 MEUR. Coal and biomass firing is stopped. The $CO_2$ emission is 7,8 Mt per year. It is almost the half of the present emission.

Setting up different objective functions we get different "optimal" power mixes. All are optimal by a Single Objective (see Table 6.).

The demonstration above shows

- This methodology is appropriate for the qualitative strategy definition
- The energy portfolio definition is a real MOO problem

Externality minimisation
The LP Problem Constraints are:
Maximum quantities in yearly TWh:
# 1 )    1 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) <= 2,2
# 2 )    0 (hydro) + 1 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) <= 2,6
# 3 )    0 (hydro) + 0 (wind) + 1 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) <= 2,2
# 4 )    0 (hydro) + 0 (wind) + 0 (biomass) + 1 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) <= 0,3
# 5 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 1 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) <= 0,4
# 6 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 1 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) <= 1,3
# 7 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 1 (nuc) + 0 (coal) + 0 (gas) <= 29,1
# 8 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 1 (coal) + 0 (gas) <= 9,9
# 9 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 1 (gas) <= 31,5
Total energy is 40 TWh
# 10 )    1 (hydro) + 1 (wind) + 1 (biomass) + 1 (PV) + 1 (geo) + 1 (biogas) + 1 (nuc) + 1 (coal) + 1 (gas) <= 40
Minimum quantities in yearly TWh:
# 11 )    1 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) >= 0,22
# 12 )    0 (hydro) + 1 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) >= 0,5
# 13 )    0 (hydro) + 0 (wind) + 1 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 0 (coal) + 0 (gas) >= 1,6
# 14 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 1 (nuc) + 0 (coal) + 0 (gas) >= 16
# 15 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 1 (coal) + 0 (gas) >= 5
# 16 )    0 (hydro) + 0 (wind) + 0 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 0 (nuc) + 1 (coal) + 0 (gas) >= 10

Fig. 15. Constraints for the optimization (constraints table)

Externality minimization solution[10]
The optimal externality value is 95,6282 (OBJ FUNCTION)
0,22  (hydro) + 0,5  (wind) + 1,6 (biomass) + 0 (PV) + 0 (geo) + 0 (biogas) + 1,6 (nuc) + 5,0 (coal) + 16,68 (gas)

Fig. 16. The optimized externality result (SOO solution)

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[10] For the demonstration the Archer's Linear Programming Tool was used

| hydro | 2,2 | TWh | biogas | 1 | TWh |
|-------|-----|-----|--------|---|-----|
| wind | 2,6 | TWh | nuc | 29,1 | TWh |
| biomass | 0 | TWh | coal | 0 | TWh |
| PV | 0,3 | TWh | gas | 14,4 | TWh |
| geo | 0,4 | TWh | EXT cost | 401,35 | MEUR |

Table 5. Yearly production rate and cost in case of externality optimization

| | $CO_2$ emission minimization | $CO_2$ emission minimization | EXT cost minimization | EXT cost minimization | INV. cost minimization | INV cost minimization | INV cost minimization | |
|---|---|---|---|---|---|---|---|---|
| Total energy | 50 | 50 | 50 | 50 | 40 | 50 | 50 | TWh |
| hydro | 2,2 | 2,2 | 2,2 | 2,2 | 0,22 | 0,22 | 2,2 | TWh |
| wind | 2,6 | 2,6 | 2,6 | 2,6 | 0,5 | 0,5 | 0,5 | TWh |
| biomass | 2,2 | 0 | 0 | 0 | 1,6 | 1,6 | 2,2 | TWh |
| PV | 0,3 | 0 | 0,3 | 0,3 | 0 | 0 | 0 | TWh |
| geo | 0,4 | 0,4 | 0,4 | 0,4 | 0 | 0 | 0,4 | TWh |
| biogas | 1,3 | 1,3 | 1,3 | 1 | 0 | 0 | 1,2 | TWh |
| nuc | 29,1 | 29,1 | 29,1 | 29,1 | 16 | 16 | 16 | TWh |
| coal | 0 | 0 | 0 | 0 | 5 | 7 | 7 | TWh |
| gas | 11,9 | 14,4 | 14,1 | 14,4 | 16,68 | 24,68 | 20,5 | TWh |
| REN | 18 % | 13 % | 13,6 % | 13 % | 5,8 % | 4,64 % | 13 % | % |
| $CO_2$ | 7,44 | 7,77 | 7,65 | 7,8 | 13,23, | 18,83 | 17,05 | Mt |
| External cost | **417,35** | **401,5** | **395,35** | **401,35** | **733,94** | **1023,94** | **952,4** | MEUR |
| Yearly power plant building cost | **182,52** | **165,94** | **174,56** | **173,17** | **95,62** | **112,96** | **125,70** | MEUR |
| Yearly power plant operation costs | **1304** | **1403** | **1383** | **1401** | **1540** | **2128** | **1882** | MEUR |

Table 6. The power generation portfolio development alternatives by different objective functions

- Instead of the politicians the numerical solution provides a good sustainable solution
- The future portfolio is not really sensitive to the amount of energy produced
- It is forbidden to build up an energetic monoculture
- In the current low cost solution the future operation costs are enormous
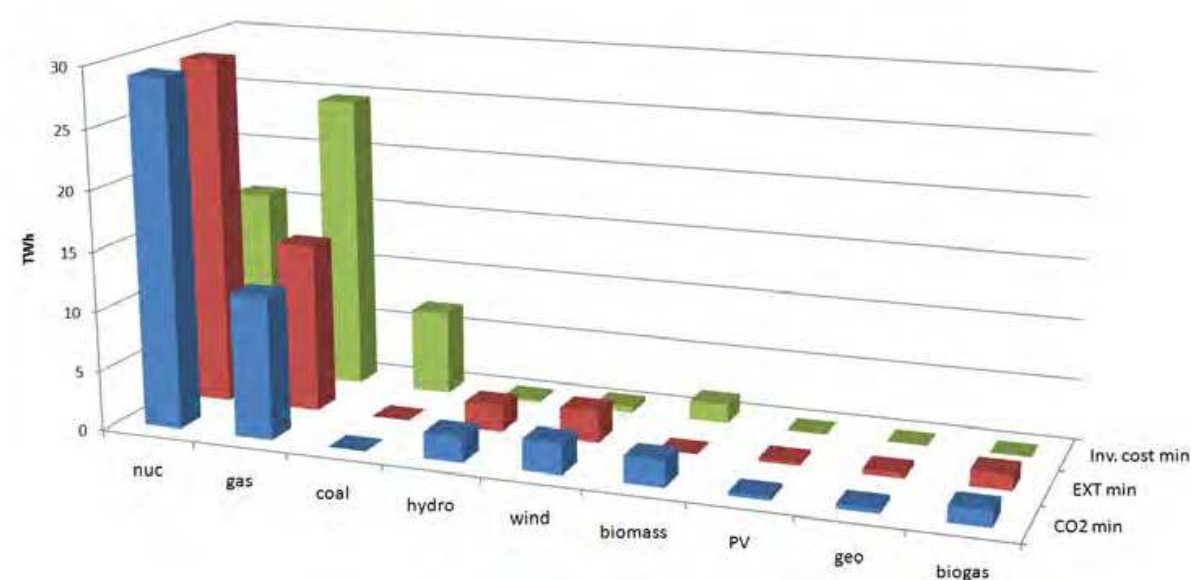- The power plant building and operation and externality costs are in the same range

Fig. 17. Visualisation of generation ratios in different optimization alternatives

The optimisation provides the mathematically optimal solution regarding a preference. We always start form the existing situation and take into account the development possibility. Fig. 17. shows e.g. that

-    We should not run any coal fired unit if we want to really decrease the $CO_2$. There is enough non $CO_2$ emittive capacities (externality and $CO_2$ minimization)
-    On the other side if we want to minimize the investment cost into the power plant (mix) than we must run this type of plants with high load factor, and we can build more gas and coal plant (minimal investment today – maximal external cost in the future).
-    The nuclear, wind and hydro capacity plays important role in the externality minimum scenarios.

Fig. 18. shows that the yearly total cost of the fossil based scenario costs more than the renewable generation solution. It comes from the high fuel cost (gas) and externality costs.
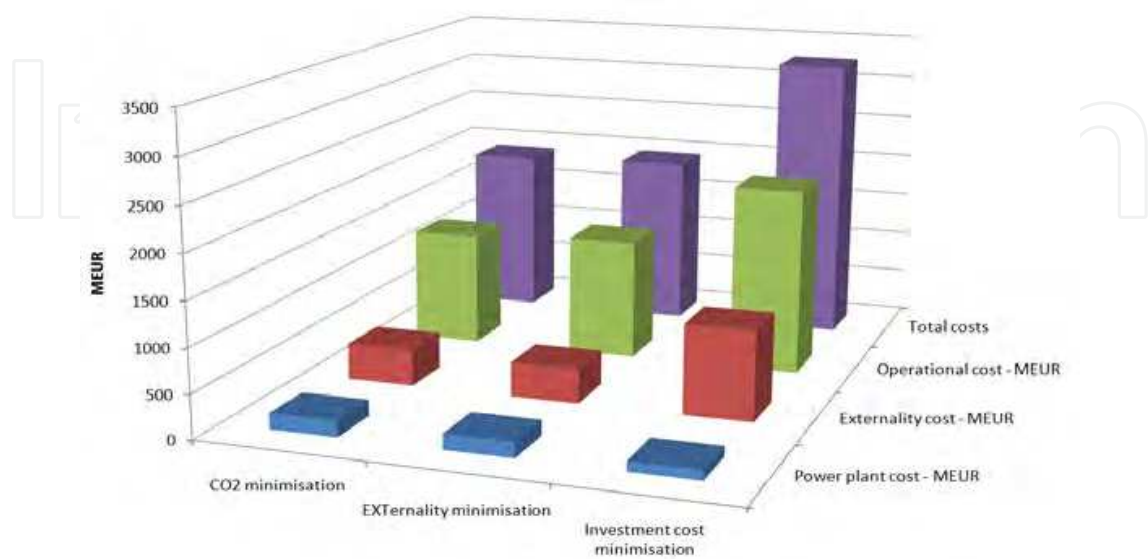


Fig. 18. Yearly costs of the alternatives (MEUR)

From the optimisation we can present other results, too. Figure 19. shows the cost efficiency of the power plant development:

*If we had 1 MEUR it is enough to …*

- …construct this amount of 'built in power capacity' … – the cheapest is the gas and coal fired plant (green column). If we take into account only the investment only into the construction, we must build more and more gas based plant. But if we count the lifecycle operation (fuel) and externality costs, this is the worst solution!
- … construct and generate this amount of energy (operation cost ~ fuel cost) – (red column) We can generate more energy from hydro, geothermal biogas and nuclear sources. The gas is the most expensive! In the long term planning hydro, geothermal biogas and nuclear (!) solutions are fitting to the relevant criteria.
- …if we pay the externality we get the previous result (blue column)
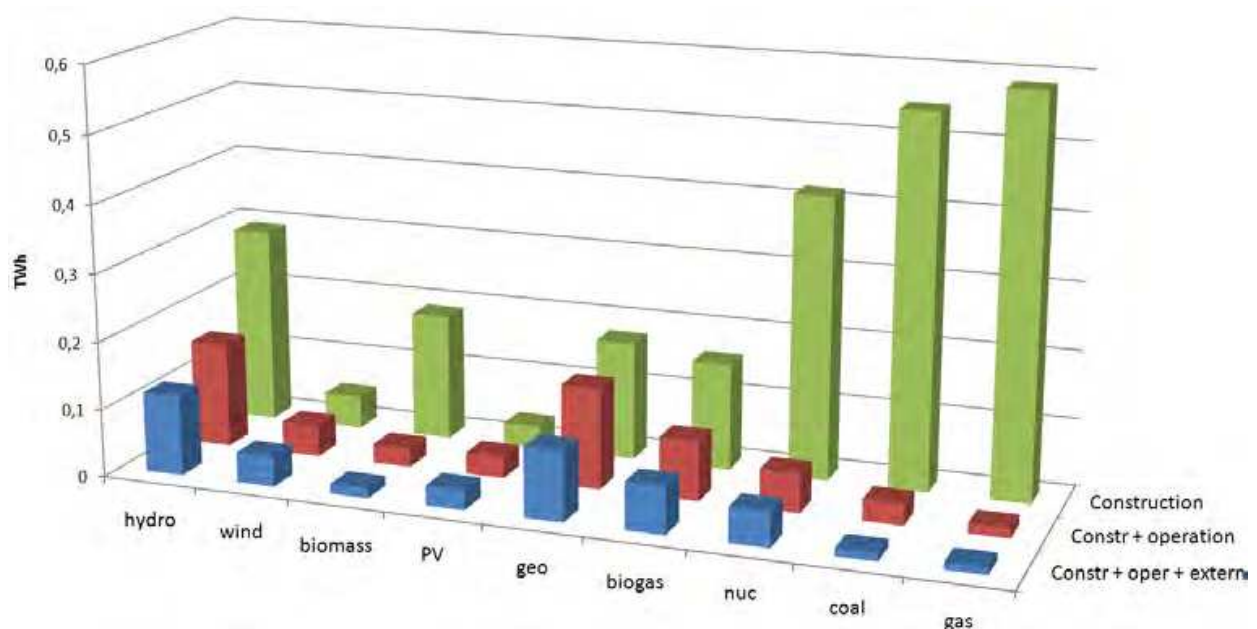


Fig. 19. How much energy can be generated from 1 MEUR?

These calculations demonstrate that the rough SOO produces really distinct scenarios so it is not recommendable to use only the cheapest OR smallest emission version.

As conclusion we can state that

- The $CO_2$ minimum and external cost minimization produces recommendable scenarios
- The simple cost minimization implies huge $CO_2$ emission
- The gas (and oil) fired plants are cheap to build but expensive to run for the fuel cost and $CO_2$ production
- The wind generation is welcome
- All portfolios contain hydro generation
- The bulk central biomass firing is not the part of optimal mix
- All the alternatives contain nuclear generation (do not forget that any other pumped storage plant raises the external costs)

More detailed optimization with exact input data provides real results. We recommend this method for the national planning level too.

## 6. New technologies

Here we count some novel, but not widely spread - over technologies that can decrease the emission of the energy industry.

There are different ways to decrease the $CO_2$ emission of the power technologies. These are:
- through the decrease of the amount of the used electricity less generation and less primary source can be enough (raising the energy efficiency, energy thriftiness)
- raising the electrical efficiency of the generation – less primary source must be burned for the same amount of electricity: Combined Heat and Power generation CHP; combined cycle power plant (CCPP); combined cycle gas turbine (CCGT)
- trapping the exhausted $CO_2$ (Clean Coal Technologies)
- changing the generation portfolio, instead of fossil fuel some $CO_2$ neutral techniques were used (nuclear, renewable)

### 6.1 Decreasing the amount of used energy

The efficiency raise helps to use less energy for keeping the same comfort level. The low consumption computer monitors, the energy saving fluorescent lamps and the heat isolation of the buildings foster this objective.

The unlimited following of the energy need requires the usage of peak power plants, too. The passive Demand Side Management (DSM) decreases the total amount of the used electricity through the efficiency raising. The active DSM reschedules the volatile power demand, the peak demand is decreased and pushed into the night time demand valley. Instead of the expensive and fossil peak generators more basic plants, e.g. nuclear plants can operate. To realize powerful demand side management in the deregulated power business environment is a great challenge (Lorrin & Willis, 1999; Shahidehpour, 2001).

The Smart metering and the Home displays can inform the customers about his energy consumption habits, so through the energy consciousness the consumption can be decreased.

The Smart grid technology accepts more renewable sources in the network, the storage technologies helps the balancing the load.

### 6.2 More energy by the same amount of $CO_2$

Traditionally electricity was generated in power plants and heat was produced in the heating central. In the co-generation approach useful electricity is also generated when some heat is needed. This is made by "traditional" gas engines (0,5-5 MW) or gas turbines (10-50 MW) with 30-50% electrical efficiency. The exhaust gas heat (mainly gas firing units) is turned into the remote heating system or industry process through heat exchangers. By co-generation almost 80-90 % of the primary energy can be harnessed.

The combined cycle technology uses the heat of the exhaust gas of the gas turbine (CCGT) but by this heat is steam generated that runs a secondary steam turbine and generator. By the utilization of the "second hand" heat the total electrical efficiency of the power plant can hit the 60 %.

### 6.3 Low emission technologies

The third way to decrease the 'per kWh $CO_2$' emission is the application of low emission power generation technologies. There are more techniques for heat and electricity generation too:

The combustion of the fossil fuel produces $CO_2$. By trapping this gas emission the energy production can be almost $CO_2$ emission free. There are new technologies under development ant test how to catch the gas: pumping it with high pressure underground storages, as depleted gas field, oil reservoirs, saline or deep sea reservoirs (Clean Coal Technologies, Carbon Capture and Storage - CCS). These methodologies decrease the overall electrical efficiency of the plant with 10-15% and require high investment cost. The final result is higher specific production cost that is not always competitive in the market.



Fig. 20. Solar through plant in San Lúcar de Mayor, Spain

### 6.4 Renewable sources

The renewable production has no $CO_2$ emission during its operation per definition. By the way in the whole life cycle (construction, maintenance, dismounting) it requires additional energy that has emission. The "during operation $CO_2$ free" technologies are the wind, PV, geothermal, biomass and the traditional hydro. Most of the renewable sources have relatively small unit power, and places spatially distributed (Lee & Scott, 2000).

*Solar irradiation*

Most of the renewable sources use the energy of the solar irradiation. The direct solar-heat-trapping heat towers are in experimental phase (see Fig. 21.). The solar trough technology is close to the commercial application (see Fig. 20.). The solar heat collectors are commercially available for decades. The global newly installed solar collector capacity in 2009 registered 48.8 million m².[11]

The sun heats the atmosphere to various temperatures, it starts turbulent flows around the globe. The wind turbines catch a part of this motion energy (see Fig. 22.). The world's total wind capacity at the end of 2009 is 150.000 MW.[12] One can't forget that the overall load factor of these plants is around 20% only.

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[11] Bank Sarasin sustainability study on the solar industry: benefiting from rising demand; http://www.sarasin.hk/internet/iesg/index_iesg/about_us_iesg/media_relation_iesg/news_iesg.htm
[12] http://www.windea.org

Fig. 21. Solar tower in San Lúcar de Mayor in Spain and solar collectors in Hungary

The photovoltaic (PV) generation origins from the semiconductor technology. The PV panels transform the solar radiation into Direct Current (DC) electricity with 7-20% efficiency. This is a superb solution for the island mode and hybrid supply (Patel, 2006) but in most cases the PV plants (up to some MW) are connected to the grid (see Fig. 23.). The yearly load factors of the PV systems are between 11-18 %. At the end of 2009 already 22.999 MW [13] PV capacity was installed all over the world. The specific generation cost closes to the traditional technologies.



Fig. 22. Wind turbine in Inota, Hungary. In the background is an old coal fired plant.

[13] Solar photovoltaic electricity empowering the world; 2011 http://www.epia.org/publications/epia-publications.html

Fig. 23. PV array in Patra, Greece

*Biomass*

The idea of the biomass based energy production is that the $CO_2$ produced by the material or gas burning after years will be built in the newly grown forest or plantation. It secure an eternal cycle, the amount of the $CO_2$ is not increasing in the atmosphere. The problem is the additional emission of the fertilization, cultivation, harvesting, transportation that never pays back. In case of biomasses not only the $CO_2$ neutrality but for the external energy input and the energy balance must by investigated too.

The primary biomasses as the forest wood (dendromass) or agricultural rests (sugarcane rest – see Fig. 24., wheat stalk, etc.) used to be burned or gasified by pyrolitic technologies. In some countries it makes the base of the renewable electricity production. For the non standardized fuel the flue gas can contain a lot of unwholesome compound. The energy balance fall over if more than 600 km of transportation of the fuel materials is necessary. The typical measure of the biomass units are between 2-30 MW. The perspective way of the biomass based energy generation is the small, distributed CHP plants.

The secondary biomasses as manure or rests of animal processing in the food industry are produced independently from the energy needs. After some months these organic materials for the disorganization turns into methane too that is a really harmful GHG. The idea of the biogas generation is to speed up this decay process by a fermentation process and then to burn the gas arose that contains approx. 70% of methane. This accelerated methane conversion (into $CO_2$) decreases the greenhouse effect and the climate change. The energy production plays second fiddle.

The metropolitan and urban life produces a large amount of wastewater that contains sludge that is hazardous waste what must be handled. The up-to-date solution is the mezofil or thermofil fermentation by bacteria that produce biogas what contains 70% of methane. This gas can be burned in gas engines (0,1 - 3 MW) producing electricity (see Fig. 25.). The end product of the process is the neutral, solid, savourless material that can be used as fertilizer in the agriculture. By this technology 30-80% of the electrical energy need of the waste water treatment can be generated so this process will not be net electricity producer.

Fig. 24. Sugarcane burning biomass power plant, Mauritius



Fig. 24. Biogas facility in Budapest, Hungary

The situation is similar at the tertiary biomasses. The recent human civilization produces millions of tons garbage, tires, sewage etc. During decades it will become methane partially. The typical handling is the unburdening. The best solution were the total recycling (zero waste city concept), the worst is the littering. A relative good solution is the incineration of the urban

garbage where the material is chemically stabilized, energy is produced (heat and electricity – see Fig. 25.), the methane is conversed into $CO_2$ and the volume is compressed in 23%.
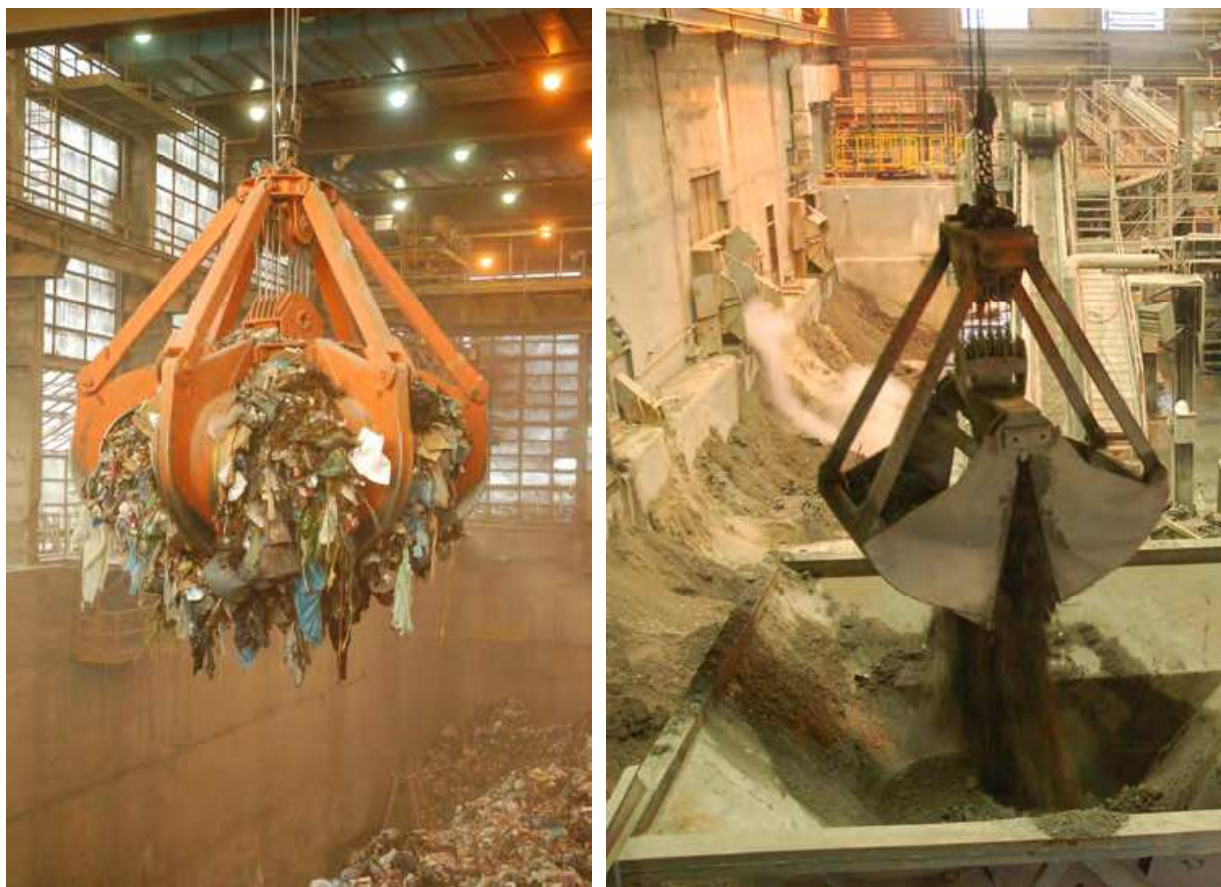


Fig. 24. Garbage before and after the incineration, Budapest, Hungary

*Geothermal energy*

The interior of the globe consist of a high temperature molten material. Some parts are not too hot, but enough hot to explore heat. The low temperature *geothermal energy* is used as hot water for heating buildings (approx. 80°C – see Fig. 25.). The high temperature water (steam approx. 150°) used directly in steam turbine (free steam emissive system) or with the help of a heat exchanger (binary system). Although the geothermal energy source in our life is unfailing, at the end of 2009 almost 10.500 MW[14] geothermal based electrical plant was installed. The typical unit measure is less than 100 MW. The fuel is priceless, for the high investment cost this type of the generation is not really competitive (expensive drilling, plant devices).

*Hydro plants*

The traditional hydro plants have the widest measure variability from some kW up to 20 GW (see Figure 26.). The hydro power is free, renewable and $CO_2$ emission free, but…

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[14] Geothermal Development Expands Globally;
 http://www.renewableenergyworld.com/rea/news/article/2009/05/geothermal-development-expands-globally

Fig. 25. Geothermal well in southern Hungary

During the last century, in the thousands of real applications a lot of experiences are gained which harmful effects should be avoided by a new hydro plant construction: water quality, earthquake, drought, agriculture, etc. The value of the water sometimes is higher than the price of the electricity that can be generated by it.
Decisions should be made warily…



Fig. 26. Hydro reservoir in Bihor Mountains, Romania

## 7. Drivers and barriers

One should ask, if the $CO_2$ emission has a significant role in the global warming, why we do not switch to low emission technologies? The power plant capacity development is demand driven, the present philosophy is: Generating as much energy as needed. The choice of the power plant type is influenced by not only the price, but the area usage, unit measure, the specific investment cost, the sensibility for the fuel price, the political stability of the fuel producing region, the water usage, the life time, etc. Among the dozens of aspects nowadays the emission is going to get more importance.

The decision about a new power plant construction (yes/no or how large, etc.) is often made in the STEPLE frame:

- **S**ocial (Employment; Right to energy access; Social mission; value of human positions - bureaucracy; etc.)
- **T**echnological (Security of supply; Quality of energy; Efficiency of production and usage; Standardisation; Integration)
- **E**conomic (Costs; End price of the energy; Growth rate of the economy; Profitability, ROI; Accumulation of the investment/development; Lifetime of the assets; etc.)
- **P**olitical (Role of the state decision/subventions; Priority of energy supply; Group interests/lobbying; National interests; etc.)
- **L**egislation (Number of the rules; Strictness of penalties; Controlled competition; Entry barriers; Corruption factor; Cooperative work between the players; etc.)
- **E**nvironmental (Greenhouse effect – EMISSION; Used/wasted materials; Area destruction; Ecological destruction; Energy resources; etc.)

The emission has weak positions nowadays…

## 8. Conclusion

In the fight for the sustainable industrialized age the energy industry has no good position. It is responsible for one third of the $CO_2$ emission and we cannot expect any change in the short future (growth of energy need, small unit measure of the renewable generation forms, relatively high direct costs). We have shown that the technologies and its emissions are well known so by a clear mathematical optimisation we could plan the optimal power mix. Also there are many $CO_2$ decreasing technologies, as the raising the energy usage and generation efficiency, trapping the exhausted $CO_2$ or changing the generation portfolio to non fossil fuels.

All the energy generation technologies have disadvantages but the decision space is wider than the simple short term profit maximization. The politicians should maximize the long term advantages (or at least to minimize the harmful effects) taking into account the long term external cost.

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**Climate Change - Research and Technology for Adaptation and Mitigation**

Edited by Dr Juan Blanco

This book provides an interdisciplinary view of how to prepare the ecological and socio-economic systems to the reality of climate change. Scientifically sound tools are needed to predict its effects on regional, rather than global, scales, as it is the level at which socio-economic plans are designed and natural ecosystem reacts. The first section of this book describes a series of methods and models to downscale the global predictions of climate change, estimate its effects on biophysical systems and monitor the changes as they occur. To reduce the magnitude of these changes, new ways of economic activity must be implemented. The second section of this book explores different options to reduce greenhouse emissions from activities such as forestry, industry and urban development. However, it is becoming increasingly clear that climate change can be minimized, but not avoided, and therefore the socio-economic systems around the world will have to adapt to the new conditions to reduce the adverse impacts to the minimum. The last section of this book explores some options for adaptation.

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