GLOBAL BALANCES

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Our planet is thought to be about 5 billion years old. From the moment of its creation, as a planet in our solar system, the earth has been undergoing a thermo-dynamic evolution, from melt mass to today's state. This evolution is continuing today, for example with volcanoes, earthquakes etc., but is not immediately observable. Human life appeared during the last 1 million years; and Homo sapiens, only in the last 10 to 15,000 years. Early human beings had to meet their energy needs by muscle power, this energy was used mainly to collect food or hunt. Since then, the population of the world has increased slowly, the main regulating factor being the available food supply.

Figure 1. Population growth during the last 8,000 years

Up to about 5000 BC, approximately 10 million food collectors and hunters were able to find food in areas with mild climates. The only mechanical energy source was human power, at about 100W (or 1 kW per day). In about 5000 BC the plough was invented. This meant that two animals (oxen), with a power of 1 kW, could produce food with the energy equivalent to 10 men. Since only one man was needed to do the ploughing, 9 others were free to do other work. The invention of the wheel created the ability to transfer products and communicate with other towns. The population grew from 10 to about 100 million. During the time of the Pharaohs in Egypt, the energy sources available were:

- Mechanical Energy, in the form of man power (slaves), horses or other animals, waterfalls and wind
- Heat, from solar energy and the burning of biomass (wood)

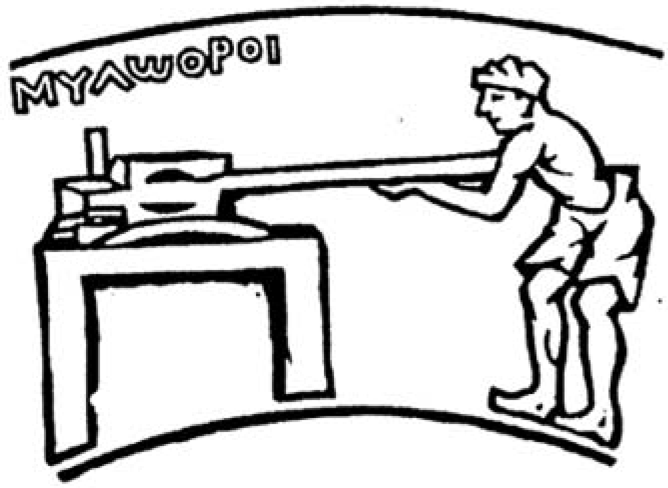

Figure 2. Early grinding machine

These energy sources remained the only ones available until about 1800 A.D. Although the development of culture and civilisation, since then, has given us the opportunity to produce and transfer science and technology, numbers did not exceed 500 million in the 18th century, even though we could feed and protect more people. But what happened in the 18th century, to trigger off this exponential population growth? J. Watt constructed a steam engine that converted heat into mechanical energy which could do heavy work, as a result of which, no human or animal effort was necessary. At that time, by burning 1 kg of coal, J. Watt could produce the same output as a strong man in 10 hours (1 kW). This was the beginning of the so called "Industrial Revolution." Steam engines could drive tractors to produce more food, could power textile machines or move railway engines and ships to transport these products, etc.

The present situation on the earth is characterised as a state of "high density" in production: for example, one fertiliser plant can cover the nutritional needs of 6 million people. In transport, tankers weighing 400,000 tonnes exist. In housing, there are cities of 30 million inhabitants. "High density" living also presupposes "high density" energy consumption. As can be seen in Figure 1, population growth parallels energy flow. 10 million MW means 2 kW for every inhabitant on the earth. Taking into consideration the fact that 50% of the energy is used is mechanical energy. This means that for every human being, 10 "energy slaves" are installed, working day and night.

As could be expected, energy use is not equally distributed, as suggested by the statistical mean value. Figures 3 and 4 show energy use in relation to the GNP of more developed countries. It is clear, without any further argument about food consumption, hospital capacity, child mortality, education, etc., that the quality of life is directly dependent on the use of energy. Development today means the use of more energy. Energy is a keyword in the political trends on our planet. The question is, do enough energy sources exist to permit the development of every nation? The answer is yes, and no. More information on energy sources and use is needed.

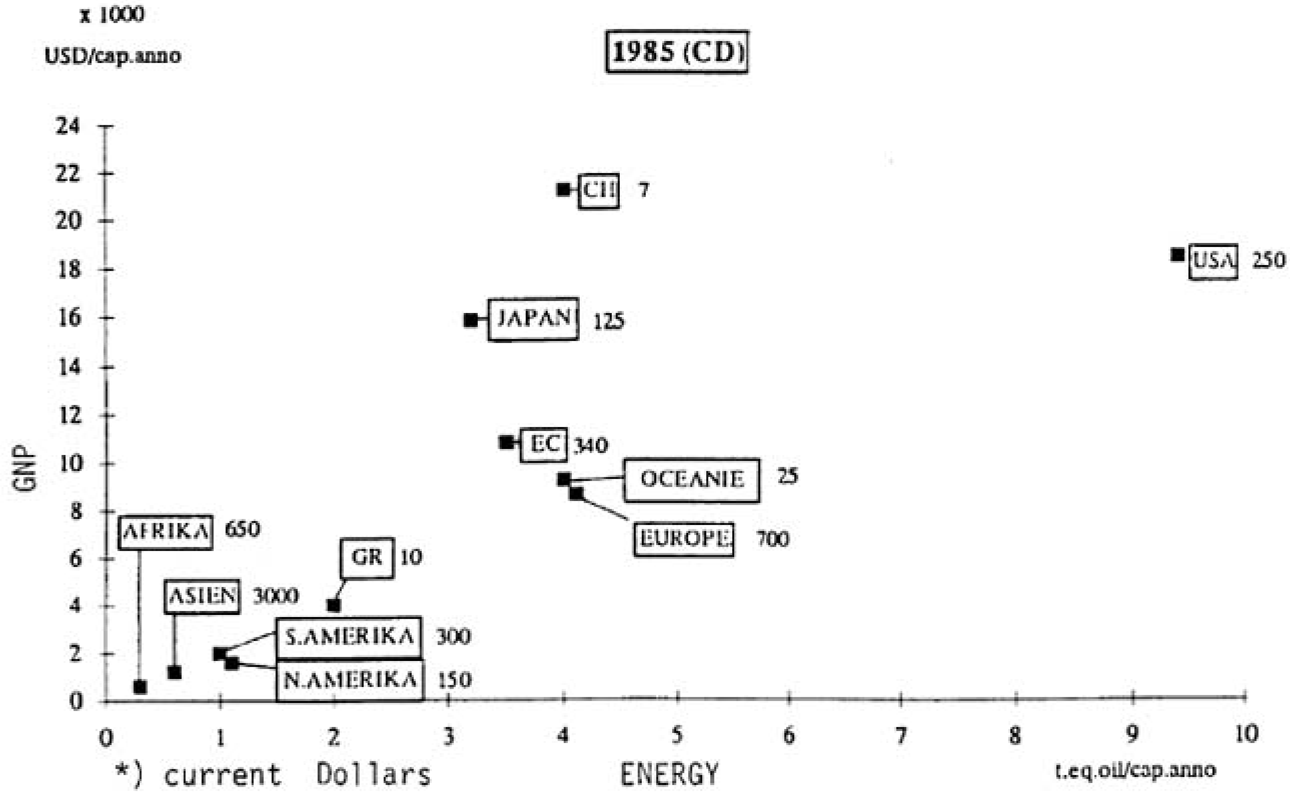

Figure 3. Energy use vs GNP in the five continents

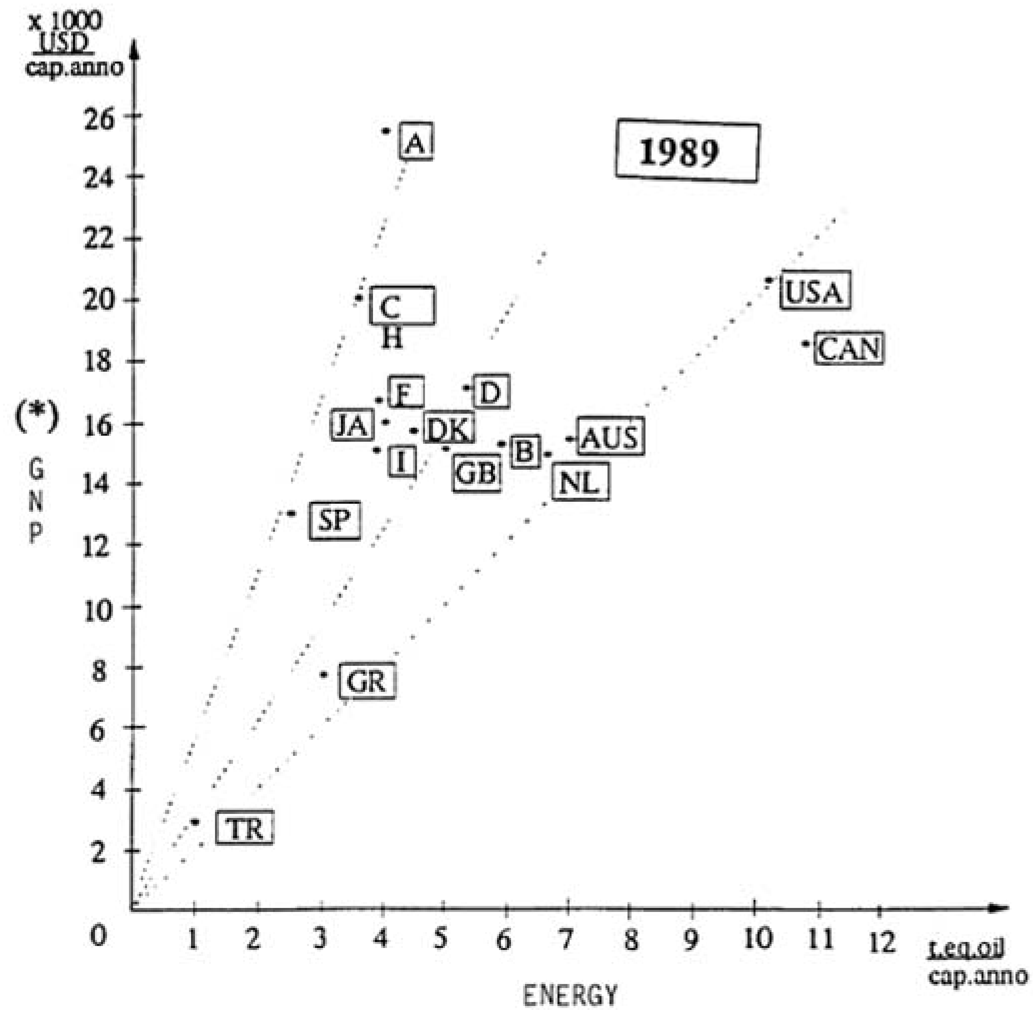

Figure 4. Energy use vs. GNP in selected regions (*) purchasing power parities

Energy Sources

The main energy source of the earth, since its creation, has been solar. In Figure 5 solar energy conversion on the earth is shown.

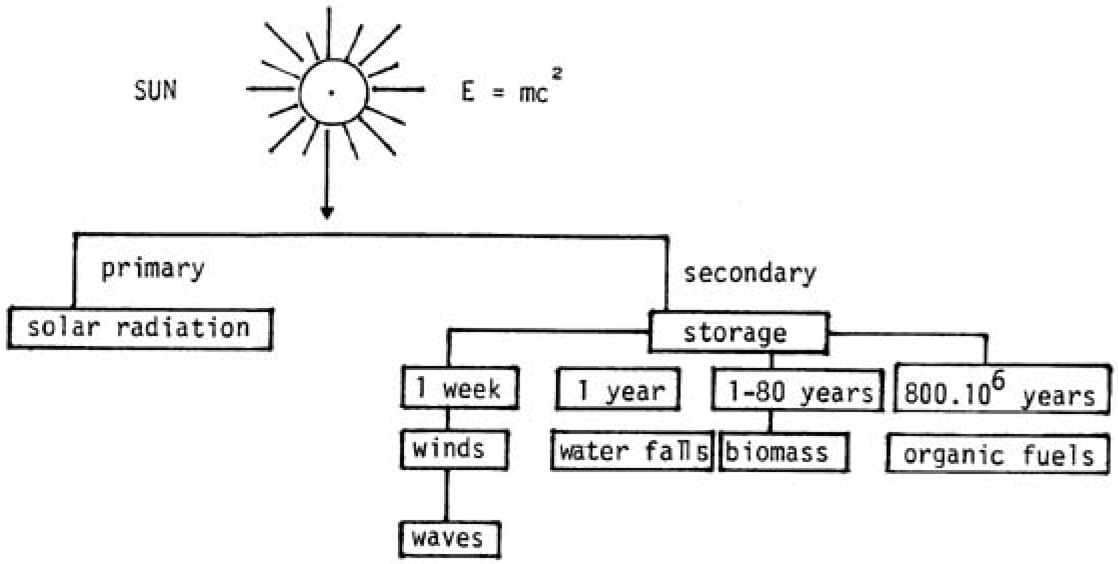

Figure 5. Solar energy conversion on earth

It is possible to differentiate between storage of 1 week and 800 million years. Biomass, stored and converted over about 800 million years, has created organic fuels such as coal, gas and oil. Organic fuels are, today, the main energy sources for human civilisation, contributing about 90 to 95% to primary energy needs.

The other energy sources are: nuclear fuels (the elements uranium and thorium) which have existed since the first moment of the earth's creation. Less significant sources are geothermal energy and tidal energy.

Figure 6 shows the different energy forms used today, as well as their potential for conversion to one another.

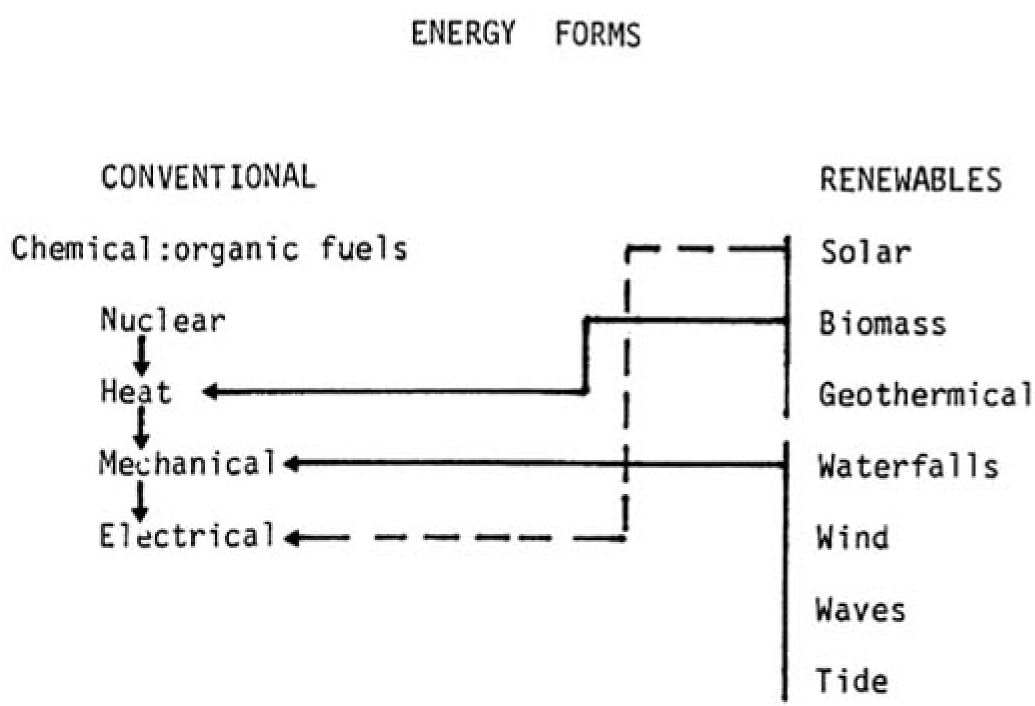

Figure 6. Energy forms and conversion potentials

Global Energy Needs

As was shown in the introduction, today 5 billion inhabitants need the energy stream (power) of 10 million MW (10TW). This unit can be defined as:

10 TW = 1 UETP (where UETP = Unit of Terrestrial Energy Power.)

This power is produced by burning organic fuels (90-92%), in nuclear power stations (3-5%) and from biomass and renewables. The conventional energy sources are not real sources, but represent stored energy. Stored energy (reserves of energy) is today, estimated to be enough to cover the energy needs of the earth for the next century, especially the oil reserves, which are mainly in the Near East (Figure 7.). On the other hand, the renewables have no time limits (values are given in Figure 5).

It is worth mentioning that the energy equivalent of biomass produced by photosynthesis is only 4 times greater than the energy stream currently used on the earth.

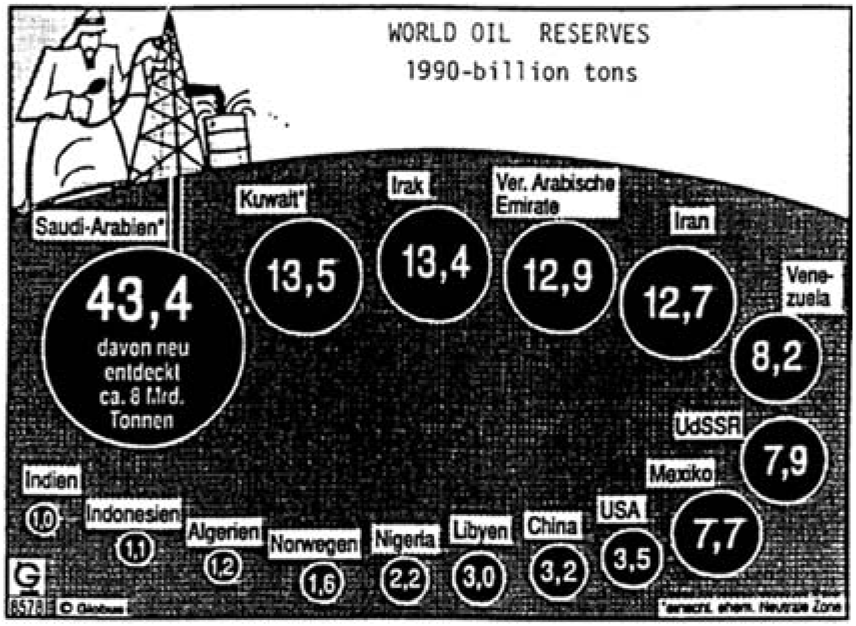

Figure 7. World oil reserves

Solar Energy	$100,000 \cdot 10^6$ MW	10,000 UETP
Biomass	$40 \cdot 10^6$ MW	4 UETP
Wind		
Water Falls	$20,000 \cdot 10^6$ MW	2,000 UETP
Waves		
Geothermy	$10 \cdot 10^6$ MW	1 UETP
Tide	$0.03 \cdot 10^6$ MW	

Figure 8. Energy streams of renewables in UETP (1 UETP=10 TW)

Global Energy Balance

The energy of the solar irradiation falling on the earth is partly reflected, while the rest is absorbed. The absorbed irradiation is transformed into heat and then totally irradiated to the universe, but now on a longer wavelength (Figure 9). The balance of energy, in-flow and out-flow, is in order to maintain a mean temperature on the earth's surface of about 15°C. The maintenance of a mean temperature of 15°C depends on the quality of the atmosphere and its permeability to short and long wavelengths of irradiation.

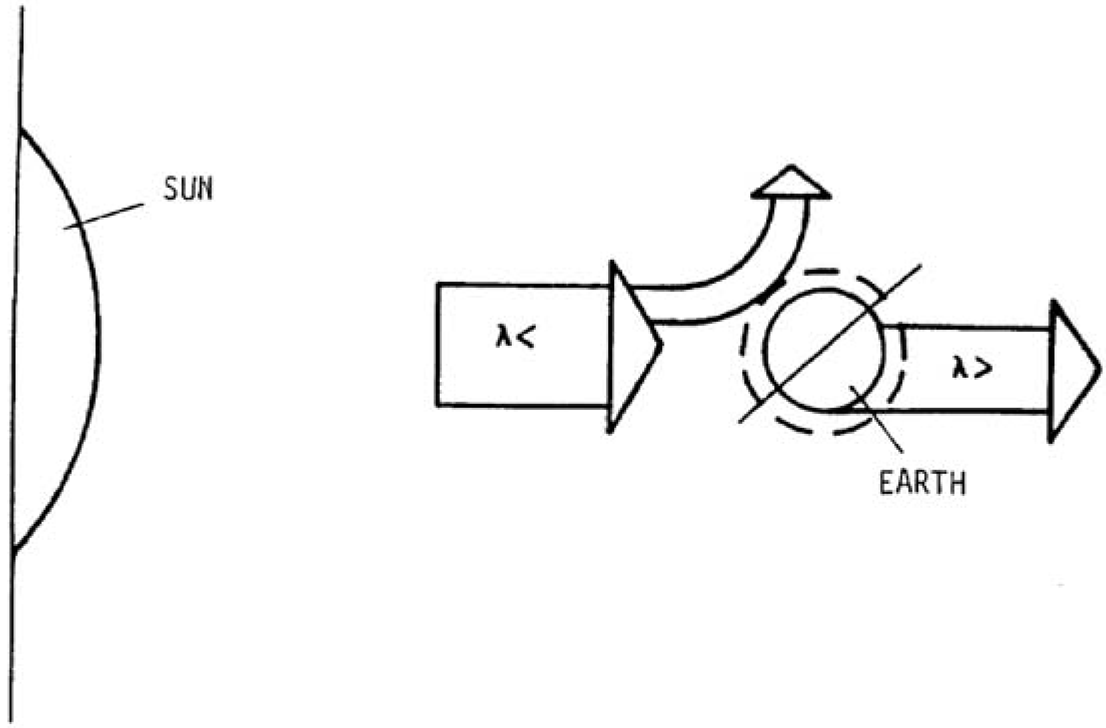

Figure 9. Global solar energy balance

Enriching the atmosphere with particles means that its permeability to short wave irradiation is less, but there is little influence on permeability to the long wave irradiation. This means that the mean temperature of the earth will fall.

The opposite effect will take place if the atmosphere is enriched by CO2 and other polyatomic gases. The O3 layer will decay due to the action of refrigerants and other polyatomic gases. It is not certain that, in the future, the earth's temperature will increase, and estimates cannot be made without exactly knowing what changes will take place in the in-flow and out-flow of the energy streams of the earth.

Water Balance

The irradiation absorbed is transformed into heat, and it is this heat which causes the surface water of the earth to evaporate. The global water balance is given in Figure 10. The total evaporation yields 512ž1015 kg/year. The water mass flowing into the ocean is 45ž1015 kg/year.

Water use, world-wide, is not equally distributed. Maximum water use, in the USA, is about 1,000 m3/cap./year. If it is reasonable to take a mean value, corresponding to the mean value of the energy use, then the world mean value of water use will be 200 m3/cap/year. Total water use amounts to: 200ž5ž109 = 1012 m3/year ÷ 1015 kg/year, or 2.2 % of water resources.

Although only 2.2 % of the fresh water is used, the problems of water pollution are acute. As a result of the unequal distribution of water resources, there is no drinking water in many districts of the world.

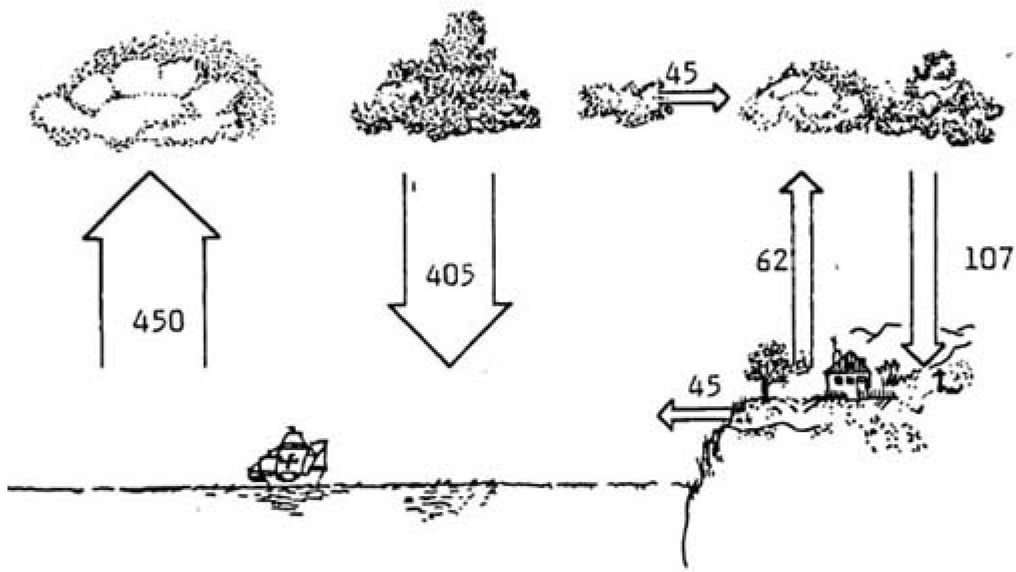

Figure 10. Global water balance (in 1015 kg/year)

Only by expensive methods, and the use of more energy, could we supply water for more people. It seems reasonable to suppose that about 10% of water resources can be used. This means that, judging by today's water use distribution, the maximum predicted population of the earth could be about 23 billion. In the event that all the population is developed, (1,000 m3/cap/year), the predicted population will be only 4.5 billion.

This means that there is no possibility of developing all existing nations, even if we were to use 5 times more water than today! There is also the problem of creating greater energy consumption, in order to supply all this water, and to treat the polluted water! We can see, also, that we have reached a point where further development will change the natural equilibrium of the earth.

Biomass Balance

It is already clear that global energy use is about one quarter of the energy equivalent of biomass production. We assume that the earth will cover its energy needs by means other than burning biomass, and that the biomass produced will be used only to produce food. The photosynthesis reaction is:

> H2O + CO2 -> [CH2O] + O2 + 635330 kJ
> 18 + 44 -> 30 + 32 [kg]

The estimated solar energy converted to biomass is:

> 40 TW or 3.5ž105 TWh/year

According to the above equation, every kg of biomass has a content of 21,177 kJ/kg or 5.88 kWh/kg. The total biomass production is:

> 3.5ž1014 / 5.88 = 6ž1013 kg/year

This biomass is produced mainly on the earth's land mass, being 1.35ž1012 m2.
The arable area of this land mass is 12%, and the potential biomass production that corresponds to it is: 0.12ž6ž103 = 7.2ž1012 kg
The specific biomass production is:

> 7.2ž1012 / 1.35ž1012 = 5.3 kg/m2 or 53 to/ha

This value is correct as total biomass production. In reality, as a result of further biological reactions with less effect, the observed values are:

	to/ha	kg/m^2
Wood	15.0	1.50
Wheat	2.2	0.22
Rice	5.8	0.58
Maize	7.0	0.70

The mean cereal production of the world is 0.3 to/cap/year. If we assume that the world is fed on cereals and that the mean production is 0.5 kg/m2, then the total food production will be 0.12ž1.35ž1014ž0.5 = 8ž1012 kg and this can feed: 8ž1012 / 300 = 27ž109 (27 billion inhabitants)

To reach this value, all arable land must be irrigated and irrigation needs are 0.8 m3/ m2/year. To irrigate 0.12ž1.35ž1014 m2 we need 1.62ž1013 m3/ year -> 1.3ž1016 kg/ year -> 13ž1015 kg/year, or 22% of the total water resources on our planet. Taking only 10% of fresh water, we reach to a figure of 12 billion inhabitants.

Oxygen Balance

The earth is spherical. The mean height of the atmosphere is about 8 km. The total volume of the atmosphere is:

VA = 5.08ž1014ž8ž1013 = 4.07ž1018 m3

The volume of the oxygen contained (21%) is

VO2 = 8.54ž1017 m3

The total mass of the atmosphere is

mA = 101,300 / 9.81 = 5.08ž1014ž10,326 = 5.25ž1018 kg

From the photosynthesis equation, we can deduce that, for every kg of oxygen consumed, 0.9375 kg of biomass are produced. Since the total mass of the atmosphere is 5.25ž1018 kg, the existing mass of oxygen is:

mO2 = 0.231ž5.25ž1018 kg = 1.21ž1017 kg

and the existing biomass:

mB = 0.9375ž1.21ž1017 kg = 1.134ž1017 kg

This value reflects the original biomass. From the original biomass, as a result of complicated chemical reactions, different fuels have been produced over a period of about 800 million years. The stored energy of the biomass on the earth is:

EB = 5.88ž1.134ž1017 kWh = 6.64ž108 TWh

Today's consumption of organic fuels is 8ž104 TWh, which means that the stored reserves will cover our needs for 8,300 years. Let us calculate the yearly balance of O2. The yearly amount of solar energy transformed into biomass energy is:

40ž106ž8,760 = 3.5ž1011 MWh = 3.5ž1014 kWh

1 kg biomass corresponds to 5.88 kWh, so the yearly production of biomass is:

mB = 3.5ž1014 kWh / 5.88 kWh/kg = 6ž1013 kg

and the mass of O2 produced is:

mO2 = 32/30ž6ž1013 kg = 6.4ž1013 kg

This corresponds to: 6.4ž1013 / 1.21ž1017 = 520ž10-6 or 520 ppm O2
25% of the oxygen produced is necessary to burn organic fuels. This amounts to 1.6ž1013 kg O2 annually!

By the time the changing pressure of O2 becomes less than 0.15 bar, life on earth will have become impossible. This means that we have a margin of 5/21 = 0.24 at our disposal, which means that we can expect to burn stored fuels for the next 2,300 years!

On the other hand, if we consider that every human being and, every animal, needs to breath 1 m3 of air per hour, in order to survive, then oxygen consumed at that rate is 0.21ž312/2.4 = 0.3 kgO2/h or 2.63ž103 kgO2/year. Consequently. the permanently feasible number of inhabitants on earth would be:

0.75ž6.4ž1013 kgO2 / 2.6ž1013 kgO2/cap. = 18.5ž109 inhabitants or 18.5 billion

Carbon-Dioxide Balance

We have postulated, that, today 80,000 TWh/year of the earth's primary energy is produced by organic fuels (coal, oil and gas). We assume that, on average, the chemical analysis of organic fuels corresponds to that of gas and oil. When burning gas or oil, 0.28 kg of CO2 is produced, for each kWh of energy delivered. The total yearly production of CO2 will be:

8ž1013ž0.28 = 2.24ž1013 kg CO2 per year, or 22.4 billion tons CO2 per year

We have established that the mass of the atmosphere is: m = 5.25ž1018 kg. The CO2 content of the air today is about 300 volume ppm, or 455 mass ppm. The total mass of CO2 is:

mCO2 = 4.55ž10-4ž5.55ž1018 = 2.4ž1015 kg

The ratio of CO2 produced to existing CO2 is:

2.24ž1013 / 2.4ž1015 = 0.93ž10-2 or approximately 1% per year

This implies that, in about 100 years, the CO2 content of the atmosphere will be twice as high as it is today. However, this is not true. The CO2 in the atmosphere is in thermodynamic equilibrium with the CO2 in water and soil. If the CO2 content goes up, then the equilibrium will shift in the direction of diluting the concentration in the air (Lechatelier's Principle). The CO2 is absorbed by the earth's oceans. At 15oC, the solubility of CO2 is 2 kg CO2/m3H2O Atm. According to Henry' s Law, 1 m3 of water can absorb: C = ëžpCO2 = 2ž0.003 = 6ž10-4 kgCO2/m3.

The oceanic area is 360ž1012 m2. The mean depth of the oceans is about 5,000 metres. The existing volume of water will be: 3.6ž1014ž5ž103 = 1.8ž1010 m3. The oceans can accept only a part of the CO2 produced yearly. Given the total water mass of the earth, we can calculate the quantity of CO2 absorption. The CO2 content in the air will be 1% higher. This means that every year 6ž10-6 kgCO2/m3H2 will be absorbed, which leads to a total CO2 absorption of 1.08ž1013 kg CO2. The yearly CO2 quantity produced is 2.24ž1013 kg. This means that about 50% of the CO2 produced is absorbed. If we take into consideration the equilibrium of CO2 in the soil, it appears improbable that there will be a big change in the CO2 content of the atmosphere.

Conclusion

An attempt has been made to calculate the global balances of energy, water, biomass, food, oxygen, and carbon dioxide. These balances give information on the present situation, on our planet, and can be used to extrapolate for the future. However, future perspectives for the earth are not clear. We cannot predict what will succeed but, we can extrapolate the global balance in two ways: If the existing population succeeds in raising global living standards, then energy needs will increase five-fold in order to satisfy water, food and other services. At the same time, pollution, will also be five times higher. If, on the other hand, the gap in living standards remains the same, then the population will grow by about five times, causing the same problems as above.

It is clear that it is time to realise that the world cannot be ruled only by local governments, but there is a need to have a global political and economic strategy. Today's world institutions are not adequate to plan or control the future development of the planet.

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Professor Vlassios Sotiropoulos studied chemistry and engineering before becoming a lecturer at Carlsruhe University, Germany. He subsequently collaborated extensively, in Germany, with large German companies, and was involved with the construction of several industrial plants. In 1978 he was appointed Professor in the Department of Engineering at Aristotle University of Thessaloniki, Greece. He is currently Head of the Energy Department of the Physical Process Laboratory, President of the Institute of Solar Technology and President of the European joint venture company MISCANTHUS. Professor Sotiropoulos has published extensively.