Zero carbon energy systems

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ZERO CARBON ENERGY SYSTEM

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1 THE STORY IN BRIEF

The present energy system – largely relying on centralized power generation facilities and fossil fuels – faces significant challenges ranging from massive inequalities in access to energy services and enormous underinvestment in energy infrastructure to air pollution responsible for some 4-

5% of the global burden of disease, security risks in various forms and greenhouse gas emissions that threaten to dangerously alter the climate balance.

In order to halt global warming, a zero carbon energy system will need to be in place by 2050 or soon thereafter. It will need to serve not the world of today but the world of 2050. How will that world look like? It is quite likely that our planet will have around 9 billion inhabitants. But many other important things are far from certain. How fast will the economy grow? What will be the living standards in various countries? What will be the prevailing preferences, values and aspirations? Will new technologies be invented and how will the old ones evolve?

Thus, we are bound to make certain assumptions and simplifications. We may, for example, assume the **business-as-usual** when the current economic and technological trends will continue and the **global demand for energy** is likely **to double** by 2050. Billions of people will still be likely to live in energy poverty without access to electricity and other modern forms of energy.

Alternatively we may imagine a future world where everyone enjoys energy services similar to an average citizen of today's developed but highly energy efficient countries like France or Japan. Such an unlikely '**fair world**' delivers high living standards for all; but it will also require **three times more energy services** than today.

Or else we may assume a world where the energy needs of the poorest people are met by most efficient technologies (on the 1kW/capita basis) whereas the rest of the world brings consumes energy at the current level of most energy-efficient developed countries. Such a '**1-kW world**' would require only about **one-third more energy** than today even when the population reaches 9 bln people.

A future energy system should be able to serve 9-10 billion people, to wipe out energy poverty, to generate zero carbon emissions, and to be introduced relatively quickly.

A 200US/tCO_2 carbon tax or similarly intensive policy measures will go a long way towards promoting zero-carbon energy. However, in order to get various constituencies on board, losers of such measures should be compensated and co-benefits of climate mitigation clearly articulated.

Yet, economic, technological and policy drivers may be insufficient to achieve both climate and developmental goals. The gap – which depends upon our vision of the future world – may be closed by lifestyle and behavior choices at the personal level and by the focus on the right vision ('the 1-kW world) at the global level.

In other words, we will in any case need more energy in the future, though whether it will be one-third or three times more (or anything in-between) depends upon our choices, assumptions and time-horizons.

If current technologies are used for this larger energy production, the emissions and concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) will raise dramatically. What we need for the sake of preserving the global climate balance is precisely the opposite: the emissions of greenhouse gases should peak by 2015, then decline by 2-7 times by 2050 and then become zero or negative by 2070. Thus a zero carbon energy system should not only serve an increasing demand but also should be introduced very quickly.

The good news is that currently available energy technologies are capable of going a long way towards this monumental objective. Under a 'carbon tax' (a proxy of policy intensity or mitigation costs) of some 200\$US/tCO_2 or similarly aggrssive policy measures, a combination of energy efficiency solutions, renewable energy production, nuclear power, and carbon capture and storage may be able to achieve the target.

The bad news are, first, that such tax or policy measures may meet fierce resistance since they represent a substantial fiscal burden (initially up to 5% of the global GDP), especially painful for certain constituencies (e.g. rapidly growing economies, many poor countries, coal-mining regions). It would be important to compensate such constituencies and to emphasize co-benefits of climate mitigation (such as energy security, health, and poverty alleviation) to get all key actors on board.

The second bad news is that carbon taxes, technological progress, and markets alone may not be sufficient to reach both climate and development targets. The gap between the vision and the economic-political-technological capabilities may need to be closed by personal choices which can probably reduce carbon emissions by dozens of percentage points in developed countries. The original size of the gap can also be reduced if the vision for the '1-kW' world is preferred to other models.

The necessary carbon reduction policies are likely to be extremely intensive and produce many bitter losers as well as some winners. Some experts consider such measures close to politically unfeasible. It is clear that the breadth (from innovation to agriculture) and the depth (evoking 'war-like' measures) of such policies should be unprecedented and that they should be contextsensitive, strategically designed and aligned with other energy, security and development challenges in order to be effective.

2 THE PRESENT ENERGY SYSTEM AND ITS CHALLENGES

In 2005, the world consumed 92 PWh of energy (International Energy Agency statistics). This did not include 30% of the global energy supply necessary to transform and distribute energy. Most energy was consumed in industry, transport and the residential sector (see figure below).

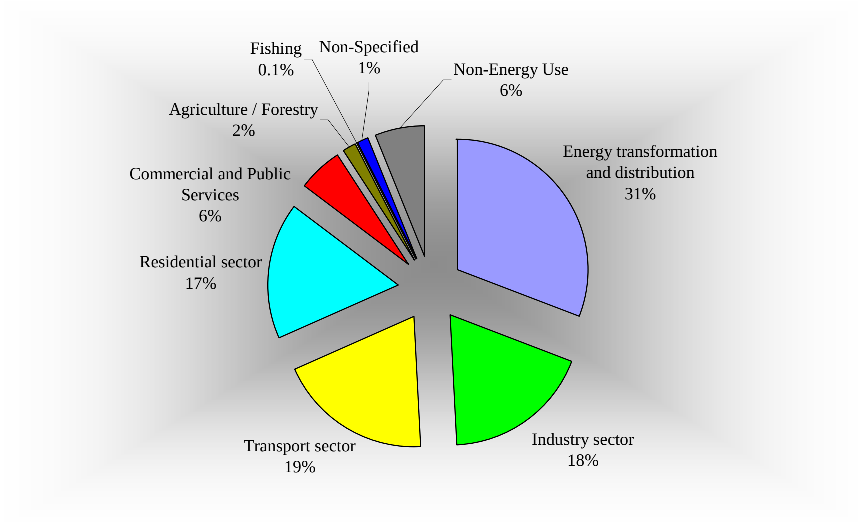
The current energy system faces a number of serious challenges (Global Energy Assessment):

- First, it is characterized **by great inequalities** in access to energy services. Approximately 2 billion people – mostly in the developing countries – still do not have access to electricity and/or clean cooking fuels. This jeopardizes poverty alleviation and achieving other Millennium Development Goals;
- Secondly, its ability to meet the growing **demand for energy services**, especially in emerging economies, is not clear. In the situation when demand for energy grows faster than available supply, the prices for energy services will rise and become more volatile jeopardizing the world economy and particularly vulnerable groups. Moreover, some experts believe that competition over the access to increasingly scarce energy resources and infrastructure may lead to increasing tensions and risks of violent conflicts. **Underinvestment** in energy infrastructure is the main reason behind declining capacity of energy systems to provide secure and reliable supply.
- Thirdly, the energy systems need to be transformed to limit **greenhouse gas emissions** (the main focus of this report) *and* at the same time adapt to inevitable changes in the climate;
- Finally, numerous adverse environmental, health[ii], security and social impacts ranging from indoor air pollution to nuclear non-proliferation concerns, accidents and involuntary resettlements should be controlled.

The two major pillars of the present energy system are fossil fuels and centralized power production facilities. These are closely connected to the major energy challenges: inequality, underinvestment, security, health and environmental impacts and global warning.

Relatively low costs of fossil fuels explain the structure of the today's energy system. If no measures are taken, these costs are not likely to become higher than costs of alternative energy in the near future.

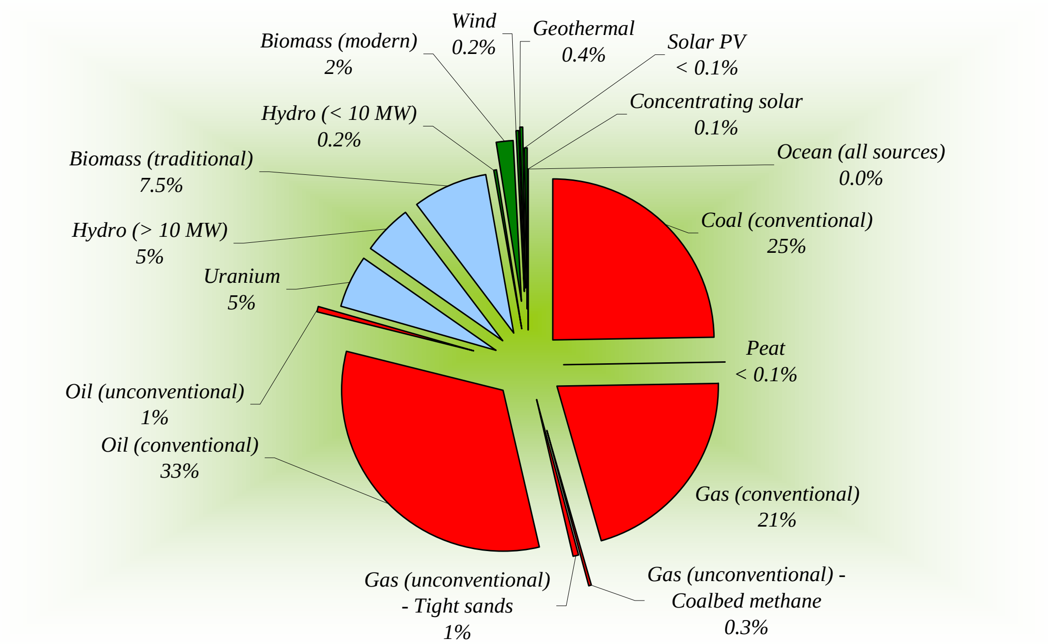
Global energy balance, 2005



Source: constructed based on the International Energy Agency (IEA) data (www.iea.org)

Most of these challenges result from the structure of the present energy supply where 80% comes from highly-carbon, conventional fossil fuels and only 3% from ‘clean’ renewable energy sources[iii] (see figure).

Sources of global energy supply, 2005

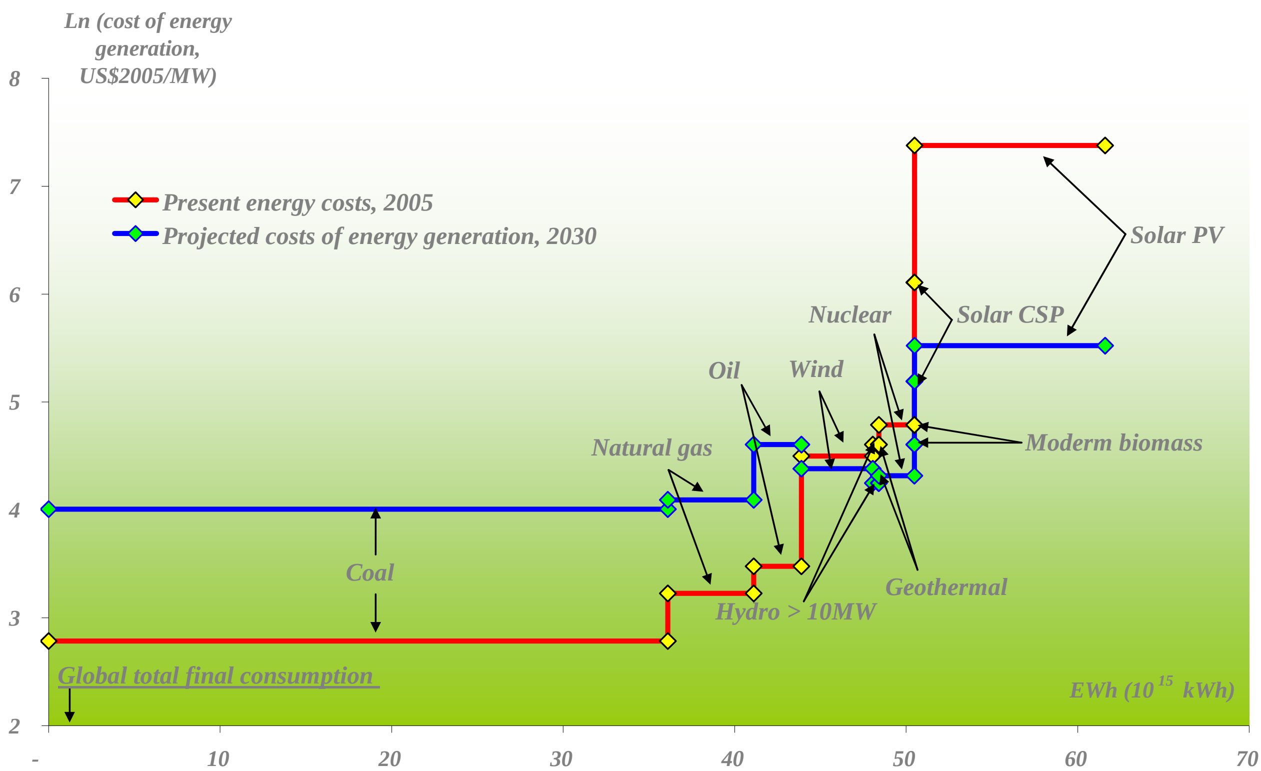


Source: Constructed based on IPCC 2007a, Chapter 4 (the figures provided in this reference are from several sources)

Note: the high-carbon fossil fuels are colored in red, low-carbon energy sources are coloured in blue (if there are serious sustainability concerns) or green (if they are believed to be environmentally sustainable).

This structure is explained by the costs of energy production as shown in the figure below. It is much cheaper nowadays to obtain energy from conventional fossil fuels, large hydropower stations and nuclear fission. Moreover, in the absence of drastic measures such a situation is not going to change in the near future (e.g. in 2030). Coal is and will remain the cheapest option for generating energy closely followed by natural gas. The cost of oil-generated energy may become comparable to that produced from wind or hydro (currently it is less), whereas the cost of solar energy will likely to remain high (Note that the costs are depicted on a logarithmic scale!).

The technical (extractable) potential of energy resources and costs of these energy carriers in present and in 2030



Source: Constructed based on IPCC 2007a, Chapter 4 (the figures provided in this reference are from several sources)

Note: The figure excludes potentially large ocean energy and biofuels because of significant uncertainties

3 THE THREE WORLDS OF TOMORROW

In conceiving a future energy system we should set our sights on the world of tomorrow, not the world of today. That world is likely to have some 9 billion people most of whom will consume more energy than their predecessors. Thus, more energy will be needed, but just *how much more* is a matter of uncertainty, assumptions, and choice.

To begin with, the world of the future can be either *forecasted* based on various models or *envisioned* based on value judgments constrained by realistic assumptions. A useful model of '**business-as-usual**' is built on a more or less uninterrupted continuation of present economic and technological trends. This model forecasts roughly a doubling of energy demand by the middle of this century.

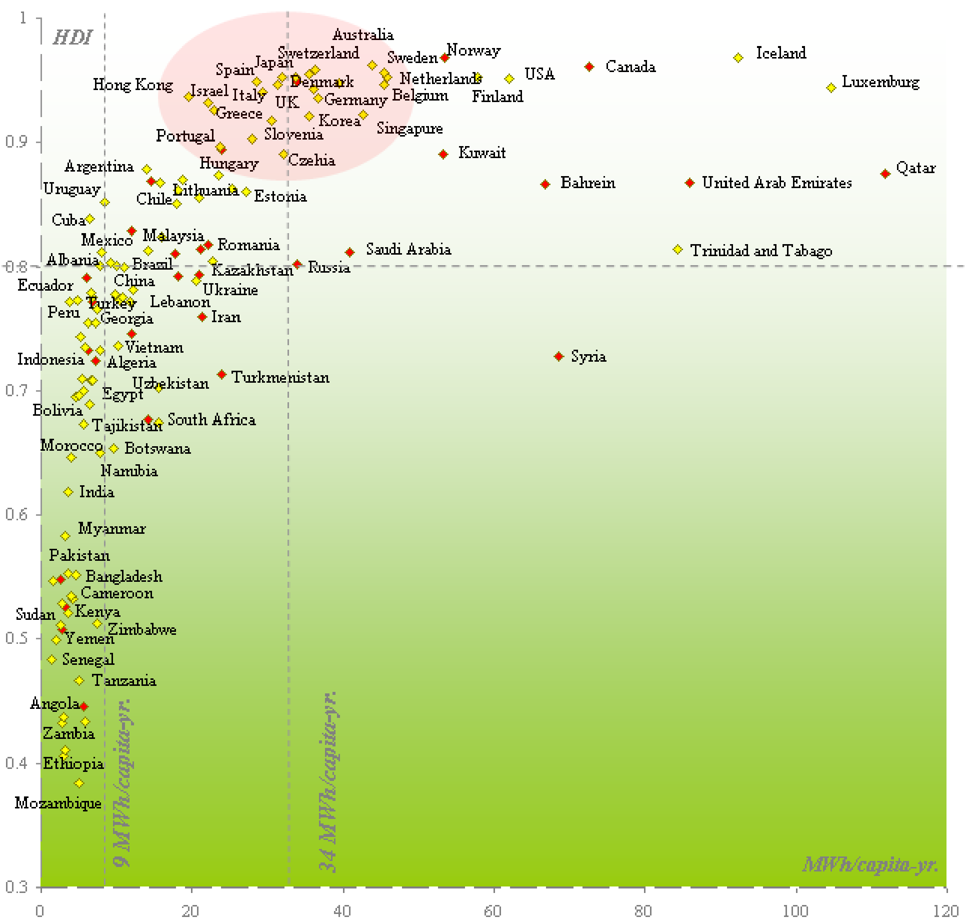
A central question for any 'envisioning' exercise is whether the present-day enormous inequalities in the energy consumption – when over 2 billion people live in energy poverty without access to electricity or other modern forms of energy – will be preserved, increased, or eliminated.

> *The world of 2050 is likely to have 9 billion people, but it is uncertain how much energy they will consume. The* ***business–as-usual*** *scenario requires twice as much energy as it is used today. A '****fair world****' where everyone enjoys the standards of living of today's France with present technologies might need 3-4 times more energy than today. A hypothetical '****one kilowatt world****' eliminates energy poverty but needs only one-third more energy than at present.*

A vision for the future energy demand may be illuminated by the link between the Human Development Index[iv] (HDI) and energy consumption which is shown in the graph below. The HDI generally grows with the rising energy consumption per capita. However, this dependence breaks at the border between the high and medium HDI (energy consumption 30-35 MWh/yr. (108-126 GJ/yr.) per capita[v]) after which HDI does not grow any longer with increase in energy consumption. One may assume that it is this level of energy consumption that is necessary for high human development which should be a right of every person.

The countries in the red circle located at this 'bending point'– such as Honk Kong, Spain, France, UK, Japan, and New Zealand – have some of the lowest per capita energy consumption on average ca 34 MWh/yr. (122 GJ/yr.) among nations with high HDIs. One way to imagine a **'fair world'** is to assume that everyone should live in conditions similar to an average citizen of such countries and consume as much energy services. The total consumption of such 'fair world' of 9 billion people – provided the technologies are unchanged – will be ca 3-4 times higher than the global energy consumption today[vi].

Human Development Index (HDI) versus energy consumption per capita, 2005



Source: Based on UNDP (2007), IEA (2007a, 2007b), UN (2008).
Note: Oil-exporting countries (net oil export is more than 5 million tonnes/yr.) are red.

However, shifting to a world with universally high quality of life may not require consuming as much energy per capita as in the developed countries. For developing countries, which still largely have to create their energy infrastructure, it is often possible to achieve dramatic improvement in living standards without a significant increase in energy use. For instance, Goldemberg *et al*. (1985) presented a thought experiment where a Sub-Saharan country could reach the quality of life of Western Europe using 1 kW/capita (ca 9 MWh/yr. or 32 GJ/yr.) that is approximately ¼ of the 'fair world' scenario. We may thus imagine a '**one-kilowatt world**' where energy poverty in the poorest countries will be eliminated on the 1 kW/capita basis[vii] whereas the energy use of the rest of the world will converge to the per capita levels of the highly efficient developed countries such as France or Japan. The total consumption of the 'one kilowatt world' in 2050 may be some 30-40% higher than the global energy consumption today.

Energy consumption of today and in the 'three worlds' of tomorrow

	Energy consumption per capita, MWh/year	Global energy consumption, TWh/year	Total CO_2 emissions per year, billion tonnes/year*
The world of today	14	92	27
	Hypothetical worlds of 2050		
Business as usual	20	186	62
The fair world	34	312	92
The one kilowatt world**	14	127	37

Note: * assuming today's carbon intensities of energy systems; ** One kilowatt world assumes that developed countries consume energy at the level of the most-efficient developed economies - 34 MWh/yr./cap. (3.9 kW/cap.) whereas developing countries reach the quality of life comparable to that of the developed world by deploying the most efficient energy technologies (as available in 1985) and consume 1 kW /cap. (8.8 MWh/cap.yr.) (see Goldemberg 1985 for detail).

4 A CLIMATE-SAFE WORLD

CO_2 emissions of any of the three future worlds described in the previous section will exceed the current level if the present day technologies and lifestyles are preserved[viii]. Yet, in order to stop climate change the CO_2 emissions should quickly start declining. How much and how rapidly depends upon the temperature increases and risks and uncertainties that we are prepared to accept.

Stabilizing the CO_2 concentration at 350-400 ppm and keeping the global temperature increase below 2-2.4°C above the pre-industrial level requires the emissions of CO_2 and other greenhouse gases to decline by ca 50-85% by 2050 and then become zero or "negative" by 2070.

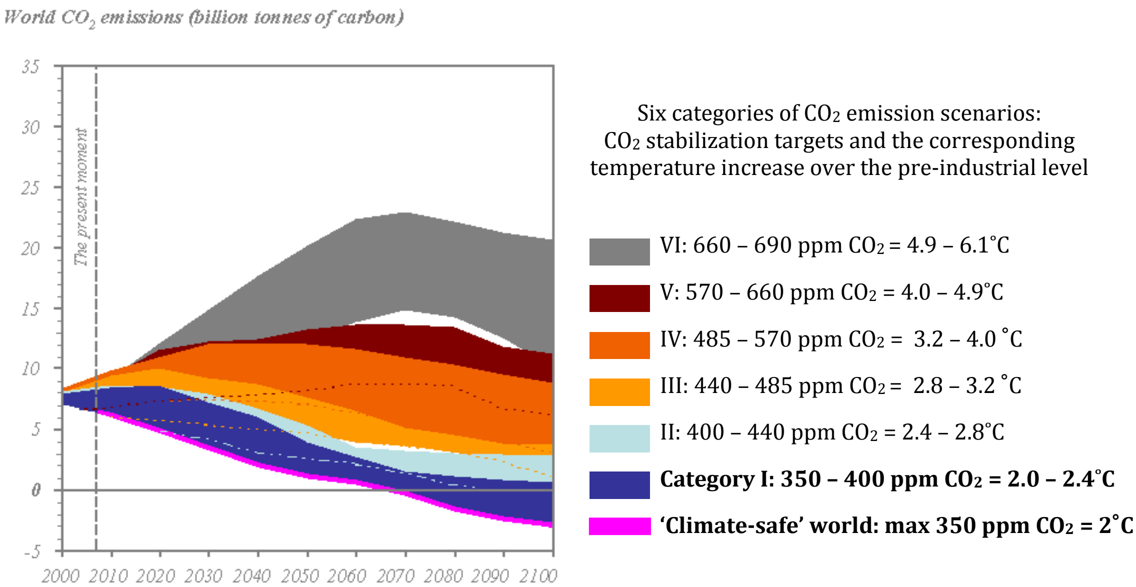
Many experts believe that to avoid dangerous and disruptive climate consequences (350 ppm of CO_2, max 2°C) the emissions will need to decline even more rapidly and profoundly.

The consensus of the Intergovernmental Panel on Climate Change (IPCC) is that allowing the global temperature to increase over 2–2.4 C as compared to the pre-industrial level[ix] would be dangerous. This means that the concentration of GHGs in the atmosphere should stabilize at 445-490 ppm[x] CO_2 -eq. (350-400 ppm of CO_2 if only this gas is considered. Note that in 2005, the concentration of CO_2 in the atmosphere was already 379 ppm (IPCC 2007b)!). The IPCC scenarios that aim to stabilize the temperature and the GHGs concentrations in this range are called *Category I scenarios*. We will use them for our core analysis since there are well-developed technology and emission forecasts linked to these scenarios.

However, before proceeding, we should note, that many experts find the IPCC analysis too conservative. They point at great uncertainties associated with climate models and potentially high risks of even the 2°C temperature rise. We will discuss the implications of this more radical view further down in the report.

The figure below illustrates the forecast of CO_2 emission scenarios allow stabilization of CO_2 concentrations in the atmosphere and respectively stabilization of the average global temperature increase at different levels. The faster and the more rapid is a decline in emissions, the lower are the levels of eventual CO_2 concentrations and temperature rises. The IPCC Category I scenarios are depicted with the dark blue ribbon. It shows that to preserve the temperature rise within 2.0-2.4°C (350-400 ppm CO_2) the global emissions would need to peak within the next 15 years, then fall by about 50-85% by 2050 (which means approximately zero for the industrialized countries by 2050), and subsequently decline further to zero or negative by 2070. More radical requirements of the 'climate-safe' world (350 ppm CO_2, max 2°C) would require a more rapid and profound decline in emissions (a purple band on the figure below). This is a challenging task given that during this century the emissions have been growing at the rate of more than 3%/yr.

Scenarios of CO_2 emissions at different stabilization levels of CO_2 concentrations and respective temperature increases over the pre-industrial level



Source: based on IPCC (2007a)

Thus, to achieve a 'climate-safe' world the energy system should *relatively rapidly* become carbon neutral. This can be achieved in the four principal ways:

1. Consuming less energy for the *same level* of energy services (improving energy efficiency);
2. Producing energy by such means that do not emit CO_2 into the atmosphere (including through capturing and storing the CO_2 emitted); and
3. Maintaining the same quality of life with *lesser* energy services (a lifestyle and behavior change).

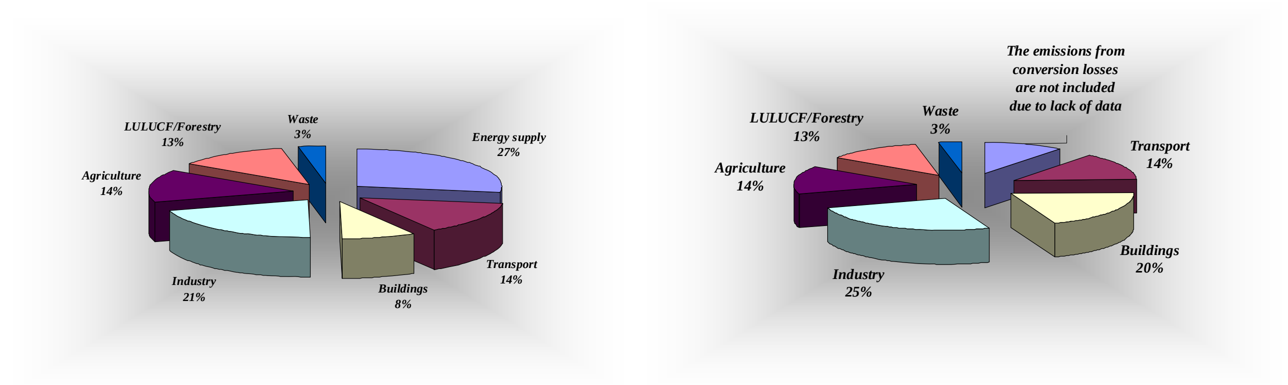
These three approaches are discussed in the next two sections.

5 COMPONENTS OF A ZERO-CARBON ENERGY SYSTEM

5.1 ENERGY TECHNOLOGIES FOR ZERO CARBON EMISSIONS

This section outlines key technologies[xi] for more efficient and less carbon intensive energy systems. The next two figures illustrate the current breakdown of emissions between different activities.

Sectoral breakdown of GHG emissions in the world: allocation according to point of the emissions (left) and end-use sectors (right)



Source: based on IPCC 2007a

Key mitigation technologies and practices: mature and emerging

Key mature technologies	Key emerging technologies
Energy supply	
Improved supply and distribution efficiency Fuel switching from coal to gas Nuclear power Renewable (hydropower, solar, wind, geothermal & bioenergy) Combined heat and power Early applications of CO_2 capture and storage	Carbon capture and storage (CCS) for gas Biomass and coal-fired electricity generation facilities: biomass or coal integrated-gasification combined-cycle systems, co-firing of biomass with coal or gas, biomass pyrolysis, supercritical steam gas plants, and others Advanced renewables (tidal and wave energy, concentrating solar, solar photovoltaics)
Industry	
More efficient electrical equipment Heat and power recovery Material recycling Control of non-CO_2 gas emissions	Advanced energy efficiency (technology optimization, operating procedures, capacity utilization) CCS for cement, ammonia, and iron manufacture Inert electrodes for aluminum manufacture
Buildings	
Efficient lighting	Integrated design of commercial buildings including

Key mature technologies	Key emerging technologies
Efficient appliances and air-conditioners Improved insulation Solar heating and cooling Alternatives for fluorinated gases	technologies, such as intelligent meters that provide feedback and control Solar photovoltaics integrated in buildings
Transport	
More fuel efficient vehicles Hybrid vehicles Biofuels More effective and attractive rail and public transport systems	Second generation biofuels Higher efficiency aircraft Advanced electric and hybrid vehicles with more powerful and reliable batteries

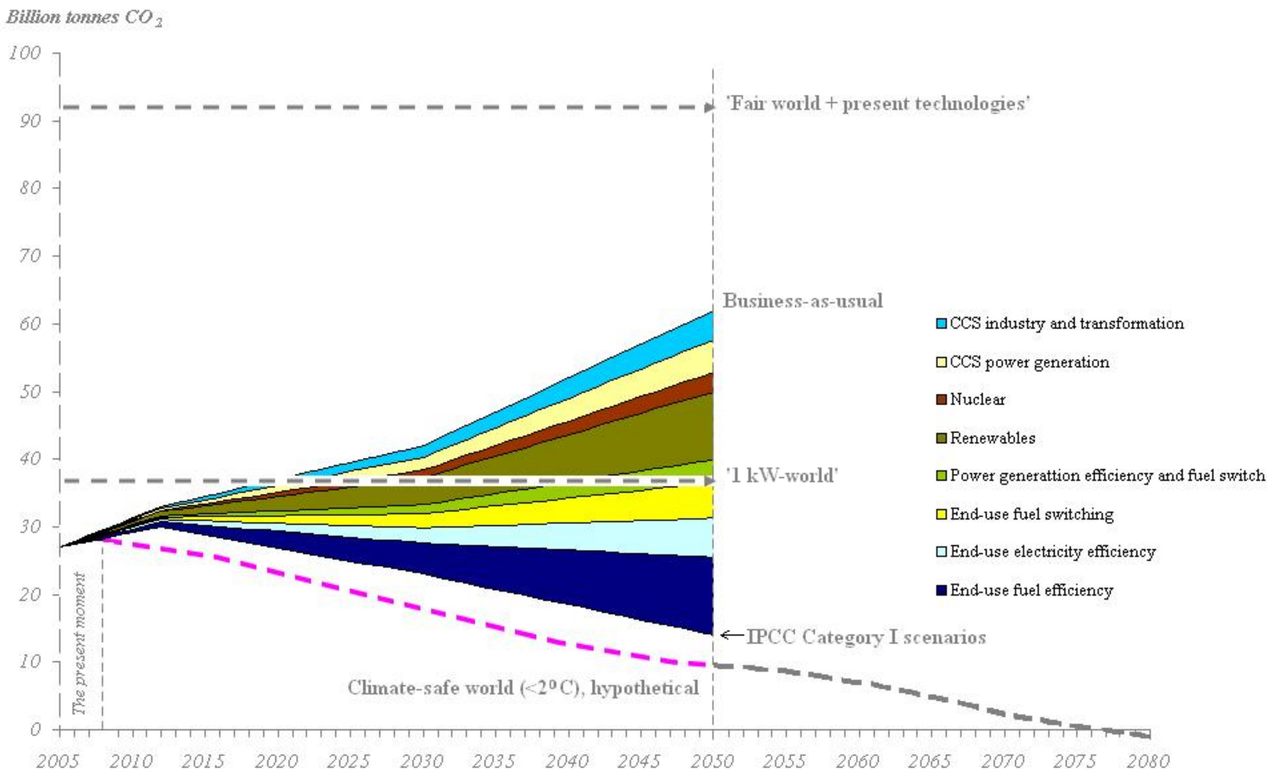
Source: based on IPCC (2007a)

In order to keep the global temperature rise below the dangerous levels all these technologies should be introduced rapidly and on a sufficiently large scale. The role and priority of each technology will be determined by the present and future energy economics.

A technology is considered *commercial* if it can, at least in principle, be deployed with profit. Today, some of the CO_2 reduction technologies are already commercial. Others need subsidies at present but may become commercial in the future provided sufficient investment in infrastructure, research, development; learning is ensured by right policies such as taxation. Thus, each technology will be able to mitigate more and more CO_2 emissions with time.

The next figure shows a scenario of introducing mitigation technologies which may be able to limit the temperature increase to 2.0–2.4°C in line with the IPCC Category I scenarios. The top line shows “the business-as-usual” baseline when no additional policy measures are implemented and the energy consumption grows with economy and population. Following the bottom line would require the deployment of most of today’s mature and emerging technologies that can become commercial given sufficiently high carbon taxes (see the discussion in the next section). In addition this scenario would require urgent implementation of unprecedented and far-reaching new policies in the energy sector.

Possible contribution of the existing mature and emerging mitigation technologies to limit the temperature increase to 2.0–2.4°C



Notes: based on IEA (2008), the hypothetical emission levels for the 'fair world', the 'one-kilowatt world', and the 'climate-safe world' explained are shown for comparison.

Thus, the highest contribution to emission reduction is expected from end-use fuel efficiency (e.g. improvement of conventional fuel boiler) and renewable energy (wind, solar, and wave) for electricity and heat. These options are followed by the improvement of electric appliances, equipment and lights and fuel switch in energy end-use sectors, for instance, fuel switch in transportation or in space and water heating and cooking in the houses. Carbon capture and storage (CCS) in the power sector and the industry may also be able reduce the emissions significantly. Finally, the efficiency improvement and fuel switch of power generation installations and nuclear electricity production have the lowest potential for GHG mitigation as compared to other advanced technologies.

Renewable energy represents especially massive opportunities if conditions are created for investors to act and the wedges could expand considerably with the right policy environment. A good example here is Germany's feed-in-system which began in 1990 and was refined in 2004. This system, for instance, made it possible for Germany to reach its installed wind capacity to ca 1/3 of the world total by the beginning of 2000. Since then and until 2008, the amount of renewable energy has tripped.

The IPCC Category I scenarios may be achieved by rapid introduction of most of the currently mature and emerging technologies for saving energy, producing it by different means, and capturing CO_2 emissions.

While some of these technologies are already commercial, others may quickly become commercial if sufficiently high carbon taxes and other policy measures are introduced.

Whether available technologies are able to ensure a climate-safe world (with CO_2 concentrations stabilized at 350 ppm) depends upon choices and assumptions on the level future energy consumption.

The figure above is based on one of the best currently existing models which forecast of the potential for emission reductions from the technological advance. It was produced by the International Energy Agency (IEA), an organization of energy importing countries. At the moment we do not have similarly robust alternative models therefore we would need to take this one as the basis for our discussion, taking into account the following:

- The IEA model describes the 'business as usual' baseline, not the emission scenarios which may be associated with alternative models; for example, the 'fair world' might result in higher emissions than 'business as usual' whereas the 'one kilowatt world' would pollute less;

- The IEA model aims to stabilize the CO_2 concentrations at 350-400 ppm whereas many experts believe that such a temperature increase is not acceptable (see the previous section).

- The IEA scenario does not run beyond 2050 (partially because the uncertainties in predicting a technological, structural, and economic change become too large), whereas stabilizing the climate requires further reduction of GHG eventually to zero and negative levels.

5.2 CLOSING THE GAP: LIFESTYLES AND PERSONAL CHOICES

A portfolio of mature and emerging technologies can help avoid a large share of the business-as-usual emissions and keep the temperature rise in the interval 2-2.4°C. However, these technologies are not enough to achieve larger emission reductions from the business-as-usual scenario and, furthermore, to reduce emissions of the 'fair' world scenario to the level of the 'climate-safe world'. Many experts argue that a significant emission reduction can results from a change in lifestyle and behavior.

Indeed, energy consumption patterns are largely determined by lifestyle. Some of the lifestyle factors are structural (e.g. the possibility to use public transport instead of personal cars), but a lot depends upon personal choices which can be exercised both in private and professional life. The Table " Carbon emissions of conventional and 'advanced' households" provided in Annex III illustrates the carbon footprint of a 4-person family. The first family is conservative, non-environmental conscious, and tends to use the conventional energy solutions. The second family uses the advanced energy solutions and chooses alternative, low-carbon options for vacation, transportation, and other services. The table concludes that the difference in lifestyle and behavior of these two families results in more than a 100%-difference in their emissions. This example illustrates that the emission reduction required by a 'fair but climate safe' world from behavioral changes are possible.

Change of lifestyles and personal choices could contribute a significant amount of CO_2 mitigation potential and it is able to 'close the gap' between the effects of technology and policy intervention and our targets of a fair and climate-safe world.

The estimates illustrated above are between two extreme cases, but nevertheless they provide an understanding of the scale of the non-technological potential for emission reduction. The gap between the 'fair' world and the climate safe world that is not closed with the technological emission reduction is ca 28 billion tones of CO_2 in 2050 or ca 3.2 tCO_2/capita. This figure is a third of the current emissions per capita of the 'model' countries' and, based on the considerations from the previous paragraph is possible to achieve.

5.3 SUMMARY: FEATURES OF A ZERO-CARBON ENERGY SYSTEMS

Though it is impossible to predict the exact configuration of technologies and arrangements that would support a zero-carbon energy system of the future, several broad generalizations can be made:

- Such a system will rely on a much broader mix of technologies than the current energy system;
- Electricity will play a much larger role in such a system;
- The future energy system is likely to feature significant 'distributed' (localized) generation of power, but also large-scale power generation and transfer over long-distances. Despite being 'distributed' it is likely to require significant international and global cooperation;
- The future energy systems is likely to use some technologies which are hitherto broadly unknown;
- The future energy system is likely to support lifestyles significantly different from the current ones in both developed and developing world.

6 COSTS AND BENEFITS OF CARBON REDUCTION

The IPCC Category I scenarios can be in principle achieved by the introduction of carbon tax of 200US/tCO_2$-eq. The investments needed for the deployment of required energy technologies is estimated at some 1% of global GDP for decades to come.

How much would it cost to achieve the desired reduction of CO_2 emissions? A rough way to answer is to identify the size of 'carbon tax' necessary to ensure the deployment of required energy technologies. Carbon tax is a charge levied on emissions of CO_2 to force their reduction. It is one of the simplest methods (save straightforward emission bans) which follows the "*polluter pays principle*" and encourages the cost-efficient emission reduction. The calculations below do not mean that we advocate the use of carbon tax as a preferred policy; we use it as *a proxy measure of 'policy intensity*. The table below shows the CO_2 emission reduction projected at different carbon tax levels.

According to available models, in order to force the IPCC Category I scenarios, the carbon tax should be set at some point between 200 and 500 US/tCO_2$-eq. depending upon the progress of emerging technologies. The carbon tax for achieving a 'fair and climate-safe world' should be set even higher, all other things being equal.

Emissions and taxes of the future worlds in 2050

Carbon tax / condition	GHG emissions
EMISSIONS OF FUTURE WORLDS (no climate measures)	
Fair world	90 billion tCO_2.eq.
Business–as-usual	60 billion tCO_2.eq.
One-kilowatt world	40 billion tCO_2.eq.
EMISSIONS REDUCTIONS DUE TO IMPOSING CARBON TAXES BY …	
20 US/tCO_2$.eq.	13 billion tCO_2.eq. (by 2030)
50 US/tCO_2$-eq.	19 billion tCO_2.eq. (by 2030)
100 US/tCO_2$-eq.	23 billion tCO_2.eq. (by 2030)
200-500US/tCO_2$-eq.	48 billion tCO_2.eq. (by 2050)
WITH THE GOAL TO ACHIEVE	
A fair and climate-safe world	Ca 10 billion tCO_2.eq. by 2050, zero by 2070

Establishing the carbon tax at the level when the mitigation technologies are expected to be commercialized (200 \$US/tCO_2-eq.) would impose a tax burden of about 5% of this global GDP each year from now until 2050 that is c. 5.5 trillion \$US/yr. This tax burden will, of course, decline (eventually to zero), as carbon emissions are reduced. The carbon tax will reach its aim only if its *revenues are targeted* at investment in emission mitigation *and if is integrated in a portfolio of instruments* aimed at poverty alleviation, economic growth, peace, and other social and economic priorities.

The revenues from investments in CO_2 emission reduction are typically estimated based on saved energy costs and revenues from the CO_2 emission credits sold. This approaches misses many co-benefits of climate mitigation. Political priority of carbon reduction can be enhanced by considering:

Carbon reduction policies are most effective when they seek to maximize numerous co-benefits of 'carbon taxes' or equivalent measures.
Such co-benefits include improved energy security, social welfare, poverty reduction, growth of productivity, new business and employment opportunities.

- Cleaner and better energy with less health impacts (e.g. 'clean cooking stoves' and modern energy services for rural Africa/Asia); better local environment (less air and water pollution, etc.); less damage to buildings and crops from pollution;
- Improved energy security (e.g. China's decision to improve efficiency by 20% in 5 years and by 15 % renewable energy by 2020 is not driven by climate considerations but concerns for energy security and local environmental problems; energy security reasons lie in the basis of the EU Energy and Climate Package adopted in January 2008)
- Reduced fuel poverty that is the problem even in the developed countries (energy savings help households reduce their utility bills and, thus, improve social welfare)
- Improved productivity (occupants of the 16 buildings studied in the UK noted that their productivity was influenced by the environment, i.e. level of lighting, heating and cooling comfort, air tightness, by between -10% and +11%[xii])

- Production, installation, and maintenance of better energy systems and infrastructure open the window to new business opportunities and create jobs. For instance, the estimated value of the emerging energy service market turnover in Europe as 5-10 billion EUR[xiii]. The European Commission[xiv] estimates one million new jobs in Europe if the EU would aim at a 20% reduction of energy consumption; another example is widely reported poverty reduction and 1 mln rural jobs in Brasil as a result of the boom in sugar-cane based ethanol production.

7. ZERO-CARBON: FROM POLICIES TO POLITICS

7.1 WHO LOSES; WHO GAINS?

The previous sections concluded that a switch to a zero-carbon world is possible though costly. The key policy question is why does is not such a switch occuring in spite of all the urgency the top-level rhetoric about the importance of the challenge. The general answer is almost obvious: because right carbon-reduction policies are likely to radically alter the world as we know it and thus – as any dramatic change – produce winners as well as losers.

It may therefore be important to clearly identify such losers and design policies in such a way as to neutralize or reduce their opposition. The Table below identifies both sides of various carbon-reduction policies and illustrates possible 'flanking' measures that could mitigate impacts on the 'losers'.

> *Carbon reduction policies are also the most effective when they adjust the distribution effects of emission reduction policies; these should ideally not increase current inequalities and not flare up conflicts.*

Even the most 'harmless' of potential measures listed in the table below (such as dissemination of clean cooking fuels and practices) that have multiple health, development and environmental benefits are likely to meet institutional opposition from aid and national agencies with other priorities (e.g. water services) and unwillingness to change established practices and procedures. Other policy measures are much more controversial. For example, the imposition of a universal 'carbon tax' has been ruled out in most democratic countries as politically unfeasible.

Winners and losers of carbon reduction policies

Type of policy	Winners	Losers	Possible 'flanking' measures
Support for 'low carbon' energy	Renewable energy, nuclear and some other energy companies	Fossil fuel and energy-intensive companies and industries	Provide support for re-profiling of energy companies
International carbon tax or similar regime	Service and knowledge-intensive economies (developed countries)	Energy- and resource-intensive economies (many developing countries)	Account for 'embedded' carbon
	Countries and regions	Countries and regions	Support for

Type of policy	Winners	Losers	Possible 'flanking' measures
	with access to significant renewable energy resources as well as with favorable geographic conditions	with little access to renewable energy resources, with adverse geographic conditions (distances, climate, etc.) and/or relying on export of fossil fuels.	diversifying oil-intensive economies
	Mature economies	Rapidly growing economies	Redistribution of the carbon tax burden, international aid
National carbon tax or similar	Richer households	Poor households	'Tax switch' schemes compensating poor households
Ban on coal production or similar	Countries/regions not dependent on coal	Coal-dependent countries/regions	Development programs in coal regions
Provision of cleaner energy (e.g. cooking fuels) to rural areas in developing countries	Target households	Other aid programmes	Shape to maximize development benefits of such programmes

The opposition is especially fierce when the systems involving fossil fuels are addressed. This is because our current lifestyle in its many aspects – ranging from individual mobility to nation states' military security – significantly depend on conventional oil, coal and natural gas. Especially in case of oil as transport fuel, there is currently no affordable low-carbon substitute. Before such substitute (widely available sustainable biofuels, commercial electric vehicles, etc.) is firmly established, the fossil-fuel based systems are unlikely to be changed.

One should also note that energy systems in general – and fossil fuel infrastructure in particular is characterized by massive investments and long pay-off times. In order to induce meaningful transformation both private and state resources need to be involved, but there should be willingness to invest under conditions of long pay-offs and large uncertainties.

The opposition is not necessarily 'the government' vs. 'the private sector'. National governments in countries with economies dependent on export of fossil fuels are likely to be lukewarm to low-carbon policies. Their political power both at home and abroad is threatened by any systemic transformation that reduces the role of oil and gas.

7.2 MEETING THE CHALLENGE

In the light of the described conflicts of interests, the question is how to realize the shift to a zero-carbon energy system? Our society has very little experience of such intensive policy-driven transformation. Many analysts agree that measures needed for zero-carbon energy systems are politically unfeasible. As the old saying attributed to a seasoned politician goes '*I know what are the right policies. I simply do not know how to get elected after I have passed them'.* Thus, this paper does not pretend to have a magic blueprint for policy-making, however, it can suggest a few necessary principles:

- Carbon-reduction policies should also serve other energy transformation needs (investment, security, access, reducing health and environmental impacts);
    - For example, providing improved cooking stoves in developing countries improves health, economy and dramatically reduces GHG emissions;
- Carbon-reduction policies should first focus on the most efficient measures with lowest economic costs;
    - For example, energy efficiency measures are usually the most efficient 'low hanging fruits' which can deliver both economic and environmental benefits without generating much opposition;
- Carbon-reduction thoughts should be integrated in various policy fields rather than only be presented as 'separate policies'.
    - For example, innovation, mobility, urban planning and agricultural policies are key for reducing carbon emissions.
- Carbon reduction policies should be introduced while the public attention is focused on the problem

- History shows that no issue is capable of controlling public opinion for more than a few years, perhaps a decade. This is a window for passing the right policies.

- Carbon reduction policies should be strategically designed and presented (including with the help of right 'allies' from the business sector and the public).

8 REFLECTIONS: REVISITING THE MESSAGE

Though this paper revolves around assumptions about the world of the future, one of its purposes is to demonstrate the role of such assumptions for present-day policies.

Our first message is that whatever world we imagine: business-as-usual, a 'fair world' or a 'one-kilowatt world', we need to reduce CO_2 emissions very radically and rapidly. True, this reduction needs to be less in case of the one-kilowatt world, but it will require no less (rather more) dramatic actions.

The second message is that no single technology or approach will be able to solve the problem. Policies should be strong enough to force a strategic change and yet flexible enough to enable innovation without backing 'favorite' solutions.

The third message is that a zero-carbon transformation will have profound implications extending beyond energy systems. There will be winners and losers, co-benefits will probably be profound and the lifestyles will need to change.

Zero-carbon energy systems will need to be driven from both bottom-up and top-down directions. The bottom-up change is about introducing distributed energy systems and communities planning for their local zero-carbon futures. The top-down change needs, first of all, be about massive investments in new energy technologies and infrastructure. Dozens of trillions of US dollars over the next few decades – an estimate that we also make in this report – is the scale necessary to ensure the transformation. Moreover, both bottom-up and top-down responses may come in unusually 'aggressive' forms reminiscent of 'war-time' measures. Consider, for example, a proposed 'Global Coal Ban' or Al Gore's recent call for civil disobedience against construction of new coal power plants without carbon capture and storage.

For sure, whatever takes us closer to zero-carbon energy systems will be extremely unusual, overstepping boundaries of our present experience with technologies, policies, economies and life-styles. We hope that this paper has thrown a bit of light onto this unchartered territory.

ANNEX I: REFERENCES

Goldemberg, J., ed. 2000. *World Energy Assessment. Energy and the challenge of sustainability*. UNDP, UNDESA, and WEC

UNDP. 2000. *World Energy Assessment, Energy and the Challenge of Sustainability, Overview update.* UNDP.

Goldemberg, J. et al. 1988. *Energy for a Sustainable World*. New York: Wiley.

Goldemberg, J., Johansson, T.B., and Reddy, A.K.N. 1985. 'Basic needs and much more with one kilowatt per capita. ***Ambio*** 14 (4-5): 190-200.

IPCC, 2007a: *Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, 2007b: Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

International Energy Agency. 2008. *Energy technology perspectives*. OECD/IEA: Paris.

International Energy Agency. 2007a. *Energy balances of OECD countries. 2004 – 2005. 2007 Edition.* OECD/IEA: Paris.

International Energy Agency. 2007b. *Energy balances of non-OECD countries. 2004 – 2005. 2007 Edition.* OECD/IEA: Paris.

International Energy Agency. 2006. *World energy outlook 2006.* IEA/OECD: Paris.

Johansson, T. B., and Goldemberg, J. ed. 2002. *Energy for sustainable development: a policy agenda.* New York : United Nations Development Programme.

Levine, M., D. Ьrge-Vorsatz, K. Blok, L. Geng, D. Harvey, S. Lang, G. Levermore, A. Mongameli Mehlwana, S. Mirasgedis, A. Novikova, J. Rilling, H. Yoshino, 2007: *Residential and commercial buildings. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. World Population Prospects: The 2006 Revision and World Urbanization Prospects. Available online.

Sims, R.E.H., Schock, R.N., Adegbululgbe, A., Fenhann, J., Konstantinaviciute, I., Moomaw, W., Nimir, H. B., Schlamadinger, B., Torres-Martнnez, J., Turner, C., Uchiyama, Y., Vuori, S.J.V., Wamukonya, S.J.V. ., and Zhang, Z. 2007: *Energy supply. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

United Nations Development Programme (UNDP). 2007. *Human Development Report 2007/2008. Fighting climate change: human solidarity in a divided world*. Pittsburg: RR Donnelley/Hoechstetter.

World Business Council for Sustainable Development. 2008. *Pathways to energy and climate 2050*. WBCSD: Geneva.

World Bank. 2006. *World Development Indicators*. WB.

ANNEX II: CONVERSION FACTORS FOR ENERGY

	GJ	Mcal	toe	MBtu	Tce
1 MWh	3.6	860	0.086	3.4	0.123

ANNEX III. SUPPLEMENTARY GRAPHS

Carbon emissions of conventional and 'advanced' households[XV]

A CONVENTIONAL HOUSEHOLD				AN ADVANCED HOUSEHOLD		
Balance, tC/yr.	**Type of savings**	**Solutions and practices**	**Solutions and practices**	**Balance, tC/yr.**	**Type of savings**	
2.57	-	Detached house with oil heating	Semi-detached house	1.57	-	
0.04	***Behavioral***	+ Extra air-conditioning				
1.48	***Behavioral***	+ Heated pool	Ground-source heat pump	-0.59	Technological	
But could install and practice				**And has install and practice**		
-0.90	Technological	Insulation and double glazing		-0.22	Technological	
-0.13	Technological	Efficient lighting		-0.09	Technological	
-0.16	Technological	Use A-class appliances		-0.11	Technological	
-0.18	***Behavioral***	Adjust thermostat		-0.04	***Behavioral***	
-0.31	***Behavioral***	Switch on/off appliances		-0.06	***Behavioral***	
And could also install				**And could also install**		
-0.34	Technological	Solar panels for electricity and water heating		-0.26	Technological	
Drivers 2 cars				**Drivers 1 car**		
1.42	-	SUV (15,000 miles)	Hybrid (5,000 miles)	0.23	Technological	
0.78	-	Sedan (10,000 miles)				
Air travel				**Air travel**		
0.73	-	~ 15 short-haul	~ 8 short-haul	0.32		
2.38	-	~ 8 long-haul				
Waste				**Waste**		
0.25	-	Waste	Waste	0.25	-	
-0.15	***Behavioral***	Recycling	Recycling	-0.15	***Behavioral***	
OVERALL, EXCL. SAVINGS: 9.65 **SAVINGS: BEHAVIORAL 0.64/TECHNOLOGICAL 1.53** **OVERALL, INCL. SAVINGS: 7.48**				**OVERALL, EXCL. SAVINGS:2.37** **SAVINGS: BEHAVIORAL 0.25/TECHNOLOGICAL 1.27** **OVERALL, INCL. SAVINGS: 0.85**		
DIFFERENCE BETWEEN BEHAVIOR OF FAMILIES RESULTS IN 4.6 tC/yr.						

Source: World Business Council for Sustainable Development 2008.

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[i] Prof. Johansson is a co-chair and Dr. Cherp is a member of the Executive Board of the Global Energy Assessment (GEA, www.globalenergyassessment.org) where Dr. Novikova is a Lead Author. However this report does not reflect the position or the findings of the GEA.

[ii] The impacts on human health from indoor air pollution in the half of the world's households that have access only to solid fuels (biomass and coal) for cooking and heating, estimated to cause 4–5 percent of the global burden of disease.

[iii] This excludes traditional biomass and large hydropower facilities.

iv The Human Development Index is an index combining normalized measures of life expectancy, literacy, educational attainment, and GDP per capita for countries worldwide.

[v] To convert this and other figures in the paper to other energy units please see the Annex I at the end of the paper.

[vi]This is a very strong call for equality since today, the 'top billion' in developed countries consume around 50% of the global primary energy whereas the 'bottom billion' in poorest developing countries consume around 4%. This argument may be subject to two further criticisms. On the one hand, it may be argued that high human development does not need to be associated with as high consumption of energy services as in the 'model countries' and thus we overestimate the future energy demand. We are partially dealing with this argument when discussing possible lifestyle changes later in the paper. The second – more serious - argument might be that we *underestimate* the amount of energy actually required. This is because the present energy consumption of the 'model countries' does not take into account, first, the energy-intensive processes which are used (in other countries) to manufacture various products that they consume and, second, energy 'sunk' in their infrastructure which was mostly built during the last century. In other words, every country cannot become a 'model country' today. This is beyond the scope of the current report to incorporate this reasoning, but it makes the whole argument in favour of a rapid and radical transformation of energy system all the more urgent.

[vii] Taking into account that the efficiency of energy infrastructure is growing whereas the number of energy uses is expanding, this figure probably would not be much different today.

[viii] Here and further in the paragraph we refer to CO_2 emissions from fuel combustion only.

[ix] The period before the year 1750.

[x] Parts per million

[xi] We list technologies of energy supply, industrial production, buildings and transport omitting agriculture, forestry, waste and waste water technologies.

[xii] Leaman and Bordass 1999 in Levine *et al*. 2007

[xiii] Butson 1998 in Levine *et al*. 2007.

[xiv] European Commission 2003, 2005; Jeninga *et al*. 1998 in Levine *et al.* 2007.

[xv] Photo credits: European Commission, Directorate General for Energy and Transport: (http://www.managenergy.net/)