ENERGY [R]EVOLUTION 2010

A SUSTAINABLE WORLD ENERGY OUTLOOK

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→| OUTLOOK

> *" Freedom is always and exclusively freedom for one who thinks differently. "*
>
> ROSA LUXEMBURG

1 ~ BACKGROUND TO ENERGY [R]EVOLUTION SCENARIOS

Nearly two years after publishing the first *Energy [R]evolution scenario* in 2007 and 2008 (Greenpeace/EREC, 2007; Krewitt et al. 2007, Krewitt et. al 2009), the new *Energy [R]evolution 2010 scenario* picks up recent trends in global socio-economic developments, and analyses to which extent they affect chances for achieving the still valid overall target: transforming our unsustainable global energy supply system into a system which complies with climate protection targets, and at the same time offers perspectives for a fair and secure access to affordable energy services in all world regions. The *Energy [R]evolution scenario* aims at demonstrating the feasibility of reducing global CO_2 emissions to 10 Gt per year in 2050, while the advanced case reduces to 3.5 Gt/y in 2050. According to IPCC findings is a prerequisite to limit global average temperature increase to well below 2°C (compared to pre-industrial level) and thus preventing dangerous anthropogenic interference with the climate system.

2 ~ THE APPROACH

Both the basic and the advanced *Energy [R]evolution scenarios* are target orientated scenarios which have been developed in a back-casting process. The main target is to reduce global CO_2 emissions to 10 Gt/a in the base case and 3.5 Gt/a in the advanced case by 2050, thus limiting global average temperature increase well below 2°C and preventing catastrophic anthropogenic interference with the climate system (Hansen et. al 2008). As we do not consider nuclear energy as an option that supports the transition towards a sustainable energy supply system, a second constraint is the phasing out of nuclear power plants until 2050.

A 10-region global energy system model implemented in the MESAP/PlaNet environment (MESAP, 2008) is used for simulating global energy supply strategies. The 10 regions correspond to the

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world regions as specified by the IEA's World Energy Outlook 2009 (Africa, China, India, Latin America, Middle East, OECD Europe, OECD North America, OECD Pacific, Rest of Developing Asia, Transition Economies) (IEA 2009a). Model calibration for the base year 2007 is based on IEA energy statistics (IEA 2009b, c). Population development projections are taken from the United Nations' World Population Prospects (UNDP 2009).

3 ~ METHODOLOGY AND ASSUMPTIONS

Three scenarios up to the year 2050 are outlined in this report: a *Reference scenario*, an *Energy [R]evolution scenario* with a target to reduce energy related CO_2 emissions by 50%, from their 1990 levels, and an *Advanced Energy [R]evolution* version which envisages a fall of more than 80% in CO_2 by 2050.

The *Reference Scenario* is based on the reference scenario in the International Energy Agency's 2009 World Energy Outlook (WEO 2009) analysis, extrapolated forward from 2030. Compared to the previous (2007) IEA projections (IEA WEO 2007), WEO 2009 assumes a slightly lower average annual growth rate of world Gross Domestic Product (GDP) of 3.1%, instead of 3.6%, over the period 2007-2030. At the same time, it expects final energy consumption in 2030 to be 6% lower than in the WEO 2007 report. China and India are expected to grow faster than other regions, followed by the Other Developing Asia group of countries, Africa and the Transition Economies (mainly the former Soviet Union). The OECD share of global purchasing power parity (PPP) adjusted GDP will decrease from 55% in 2007 to 29% by 2050.

The *Energy [R]evolution Scenario* has a key target of 50% renewables by 2050. A second objective is the global phasing out of nuclear energy. To achieve these goals the scenario is characterised by significant efforts to fully exploit the large potential for energy efficiency. At the same time, all cost-effective renewable energy sources are used for heat and electricity generation, as well as the production of bio fuels. The general framework parameters for population and GDP growth remain unchanged from the Reference scenario.

The *Advanced Energy [R]evolution Scenario* takes a much more radical approach to the climate crisis facing the world and therefore assumes much shorter technical lifetimes for coal-fired power plants – 20 years instead of 40 years. To fill the resulting gap, the annual growth rates of renewable energy sources, especially solar photovoltaics, wind and concentrating solar power plants, have therefore been increased. Apart from that, the advanced scenario takes on board all the general framework parameters of population and economic growth from the basic version, as well as most of the energy efficiency roadmap. In the transport sector, however, there is 15 to 20% lower final energy demand until 2050 due to a combination of simply less driving and instead increase use of public transport and a faster uptake of efficient combustion vehicles and – after 2025 – a larger share of electric vehicles. Within the heating sector there is a faster expansion of CHP in the industry sector, more electricity for process heat and a faster growth of solar and geothermal heating systems. Combined with a larger share of electric drives in the transport sector, this results in a higher overall demand for power. Even so, the overall global electricity demand in the *Advanced Energy [R]evolution scenario* is still lower than in the *Reference scenario*. In the advanced scenario the latest market development projections of the renewable industry (5) have been calculated for all sectors The speedier uptake of electric and hydrogen vehicles, combined with the faster implementation of smart grids and expanding super grids (about ten years ahead of the basic version) allows a higher share of fluctuating renewable power generation (photovoltaic and wind). The threshold of a 40% proportion of renewables in global primary energy supply is therefore passed just after 2030 (also ten years ahead). By contrast, the quantity of biomass and large hydro power remain the same in both *Energy [R]evolution scenarios*, for sustainability reasons.

OIL AND GAS PRICE PROJECTIONS

The recent dramatic fluctuations in global oil prices have resulted in slightly higher forward price projections for fossil fuels. Under the 2004 'high oil and gas price' scenario from the European Commission, for example, an oil price of just $34 per barrel was assumed in 2030. More recent projections of oil prices by 2030 in the IEA's WEO 2009 range from $2008 80/bbl in the lower prices sensitivity case up to $2008 150/bbl in the higher prices sensitivity case. The reference scenario in WEO 2009 predicts an oil price of $2008 115/bbl. Since the first Energy [R]evolution study was published in 2007, however, the actual price of oil has moved over $100/bbl for the first time, and in July 2008 reached a record high of more than $140/bbl. Although oil prices fell back to $100/bbl in September 2008 and around $80/bbl in April 2010 the projections in the IEA reference scenario might still be considered too conservative. Taking into account the growing global demand for oil we have assumed a price development path for fossil fuels based on the IEA WEO 2009 higher prices sensitivity case extrapolated forward to 2050 (see TABLE 1). As the supply of natural gas is limited by the availability of pipeline infrastructure, there is no world market price for gas. In most regions of the world the gas price is directly tied to the price of oil. Gas prices are therefore assumed to increase to $24-29/GJ by 2050.

	UNIT	2000	2005	2007	2008	2010	2015	2020	2025	2030	2040	2050
CRUDE OIL IMPORTS	barrel											
IEA WEO 2009 "Reference"		34.30	50.00	75.00	97.19		86.67	100	107.5	115		
USA EIA 2008 "Reference"						86.64		69.96		82,53		
USA EIA 2008 "High Price"						92.56		119.75		138.96		
Energy [R]evolution 2010							110.56	130.00	140.00	150.00	150.00	150.00
NATURAL GAS IMPORTS												
IEA WEO 2009 "Reference"												
United States	GJ	5.00	2.32	3.24	8.25		7.29	8.87	10.04	11.36		
Europe	GJ	3.70	4.49	6.29	10.32		10.46	12.10	13.09	14.02		
Japan LNG	GJ	6.10	4.52	6.33	12.64		11.91	13.75	14.83	15.87		
Energy [R]evolution 2010												
United States	GJ			3.24		8.75		10.70	12.40	14.38	18.10	23.73
Europe	GJ			6.29		10.87		16.56	17.99	19.29	22.00	26.03
Japan LNG	GJ			6.33		13.34		18.84	20.37	21.84	24.80	29.30
HARD COAL IMPORTS												
OECD steam coal imports	tonne											
Energy [R]evolution 2010	tonne			69.45		120.59	116.15	135.41	139.50	142.70	160.00	172.30
IEA WEO 2009 "Reference"	tonne	41.22	49.61	69.45		120.59	91.05	104.16	107.12	109.4		
BIOMASS (SOLID)												
Energy [R]evolution 2010												
OECD Europe	GJ			7.4		7.7	8.2	9.2		10.0	10.3	10.5
OECD Pacific and North America	GJ			3.3		3.4	3.5	3.8		4.3	4.7	5.2
Other regions	GJ			2.7		2.8	3.2	3.5		4.0	4.6	4.9

SOURCE 2000-2030, IEA WEO 2009 HIHER PRICES SENSITIVITY CASE FOR CRUDE OIL, GAS AND STEAM COAL; 2040-2050 AND OTHET FUELS, OWN ASSUMPTIONS.

TABLE 1 - **FOSSIL FUEL PRICE ASSUMPTIONS FOR THE THREE SCENARIOS**

COST OF CO2 EMISSIONS

Assuming that a CO2 emissions trading system is established across all world regions in the longer term, the cost of CO2 allowances needs to be included in the calculation of electricity generation costs. Projections of emissions costs are even more uncertain than energy prices, however, and available studies span a broad range of future estimates. As in the previous Energy [R]evolution study we assume CO2 costs of $10/tCO2 in 2015, rising to $50/tCO2 by 2050. Additional CO2 costs are applied in Kyoto Protocol Non-Annex B (developing) countries only after 2020.

PROJECTIONS OF FUTURE INVESTMENT COSTS FOR POWER GENERATION FOSSIL FUEL POWER PLANTS

While the fossil fuel power technologies in use today for coal, gas, lignite and oil are established and at an advanced stage of market development, further cost reduction potentials are assumed. The potential for cost reductions is limited, however, and will be achieved mainly through an increase in efficiency.

TABLE 2 summarises our assumptions on the technical and economic parameters of future fossil-fuelled power plant technologies. In spite of growing raw material prices, we assume that further technical innovation will result in a moderate reduction of future investment costs as well as improved power plant efficiencies. These improvements are, however, outweighed by the expected increase in fossil fuel prices, resulting in a significant rise in electricity generation costs.

RENEWABLES

TABLE 2 summarises the cost trends for renewable energy technologies as derived from the respective learning curves. It should be emphasised that the expected cost reduction is basically not a function of time, but of cumulative capacity, so dynamic market development is required. Most of the technologies will be able to reduce their specific investment costs to between 30% and 70% of current levels by 2020, and to between 20% and 60% once they have achieved full maturity (after 2040). Reduced investment costs for renewable energy technologies lead directly to reduced heat and electricity generation costs, as

TABLE 2 - **DEVELOPMENT OF EFFICIENCY AND INVESTMENT COSTS FOR SELECTED POWER PLANT TECHNOLOGIES**

		2007	2015	2020	2030	2040	2050
Coal-fired condensing power plant	Efficency (%)	45	46	48	50	52	53
	Ivestment costs ($/kW)	1,320	1,230	1,190	1,160	1,130	1,100
	Electricity generation costs including CO2 emission costs ($cents/kWh)	6.6	9.0	10.8	12.5	14.2	15.7
	CO2 emissions* (g/kWh)	744	728	697	670	644	632
Lignite-fired condensing power plant	Efficency (%)	41	43	44	44.5	45	45
	Ivestment costs ($/kW)	1,570	1,440	1,380	1,350	1,320	1,290
	Electricity generation costs including CO2 emission costs ($cents/kWh)	5.9	6.5	7.5	8.4	9.3	10.3
	CO2 emissions (g/kWh)	975	929	908	898	888	888
Natural gas combined cycle	Efficency (%)	57	59	61	62	63	64
	Ivestment costs ($/kW)	690	675	645	610	580	550
	Electricity generation costs including CO2 emission costs ($cents/kWh)	7.5	10.5	12.7	15.3	17.4	18.9
	CO2 emissions (g/kWh)	354	342	330	325	320	315

SOURCE: DLR, 2010 | *CO emission refer to power station outputs only. Life-cycle emission are not considered.

TABLE 3 - **PROJECTED COST DEVELOPMENT FOR RENEWABLE POWER GENERATION TECHNOLOGIES, MARKET VOLUMES AND INVESTMENTS**

PHOTOVOLTAICS (PV)		2007	2015	2020	2030	2040	2050
	ENERGY [R]EVOLUTION						
Global installed capacity	GW	6	98	335	1036	1915	**2968**
Investment costs	$/kWp	3.746	2.610	1.776	1.027	785	**761**
Operation and maintenance costs	$/kW/a	66	38	16	13	11	**10**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity	GW	6	108	439	1330	2959	**4318**
Investment costs	$/kWp	3.746	2.610	1.776	1.027	761	**738**
Operation and maintenance costs	$/kW/a	66	38	16	13	11	**10**

CONCENTRATING SOLAR POWER (CSP)		2007	2015	2020	2030	2040	2050
	ENERGY [R]EVOLUTION						
Global installed capacity	GW	1	25	105	324	647	**1002**
Investment costs	$/kWp	7.250	5.576	5.044	4.263	4.200	**4.160**
Operation and maintenance costs	$/kW/a	300	250	210	180	160	**155**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity	GW	1	28	225	605	1173	**1643**
Investment costs	$/kWp	7.250	5.576	5.044	4.200	4.160	**4121**
Operation and maintenance costs	$/kW/a	300	250	210	180	160	**155**

WIND POWER		2007	2015	2020	2030	2040	2050
	ENERGY [R]EVOLUTION						
Global installed capacity (on + offhsore)	GW	95	407	878	1733	2409	**2943**
Investment costs - onshore	$/kWp	1.510	1.255	998	952	906	**894**
Operation and maintenance costs - onshore	$/kW/a	58	51	45	43	41	**41**
Investment costs - offshore	$/kWp	2900	2200	1540	1460	1330	**1305**
Operation and maintenance costs - offshore	$/kW/a	166	153	114	97	88	**83**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity (on + offhsore)	GW	95	494	1140	2241	3054	**3754**
Investment costs - onshore	$/kWp	1.510	1.255	998	906	894	**882**
Operation and maintenance costs - onshore	$/kW/a	58	51	45	43	41	**41**
Investment costs - offshore	$/kWp	2900	2200	1540	1460	1330	**1305**
Operation and maintenance costs - offshore	$/kW/a	166	153	114	97	88	**83**

BIOMASS		2007	2015	2020	2030	2040	20500
	ENERGY [R]EVOLUTION						
Global installed capacity - electricity only	GW	28	48	62	75	87	**107**
Investment costs	$/kWp	2818	2452	2435	2377	2349	**2326**
Operation and maintenance costs	$/kW/a	183	166	152	148	147	**146**
Global installed capacity - CHP	GW	18	67	150	261	413	**545**
Investment costs	$/kWp	5250	4255	3722	3250	2996	**2846**
Operation and maintenance costs	$/kW/a	404	348	271	236	218	**207**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity - electricity only	GW	28	50	64	78	83	**81**
Investment costs	$/kWp	2818	2452	2435	2377	2349	**2326**
Operation and maintenance costs	$/kW/a	183	166	152	148	147	**146**
Global installed capacity - CHP	GW	18	65	150	265	418	**540**
Investment costs	$/kWp	5250	4255	3722	3250	2996	**2846**
Operation and maintenance costs	$/kW/a	404	348	271	236	218	**207**

GEOTHERMAL		2007	2015	2020	2030	2040	2050
	ENERGY [R]EVOLUTION						
Global installed capacity - electricity only	GW	10	19	36	71	114	**144**
Investment costs	$/kWp	12.446	10.875	9.184	7.250	6.042	**5.196**
Operation and maintenance costs	$/kW/a	645	557	428	375	351	**332**
Global installed capacity - CHP	GW	1	3	13	37	83	**134**
Investment costs	$/kWp	12.688	11.117	9.425	7.492	6.283	**5.438**
Operation and maintenance costs	$/kW/a	647	483	351	294	256	**233**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity - electricity only	GW	10	21	57	191	337	**459**
Investment costs	$/kWp	12.446	10875	9184	5.196	4.469	**3.843**
Operation and maintenance costs	$/kW/a	645	557	428	375	351	**332**
Global installed capacity - CHP	GW	0	3	13	47	132	**234**
Investment costs	$/kWp	12.688	11.117	9.425	7.492	6.283	**5.438**
Operation and maintenance costs	$/kW/a	647	483	351	294	256	**233**

OCEAN ENERGY		2007	2015	2020	2030	2040	2050
	ENERGY [R]EVOLUTION						
Global installed capacity	GW	0	9	29	73	168	**303**
Investment costs	$/kWp	7.216	3.892	2.806	2.158	1.802	**1.605**
Operation and maintenance costs	$/kW/a	360	207	117	89	75	**66**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity	GW	0	9	58	180	425	**748**
Investment costs	$/kWp	7.216	3.892	2.806	1.802	1.605	**1.429**
Operation and maintenance costs	$/kW/a	360	207	117	89	75	**66**

HYDRO		2007	2015	2020	2030	2040	2050
	ENERGY [R]EVOLUTION						
Global installed capacity	GW	922	1043	1206	1307	1387	**1438**
Investment costs	$/kWp	2.705	2.864	2.952	3.085	3.196	**3.294**
Operation and maintenance costs	$/kW/a	110	115	123	128	133	**137**
	ADVANCED ENERGY [R]EVOLUTION						
Global installed capacity	GW	922	1111	1212	1316	1406	**1451**
Investment costs	$/kWp	2.705	2.864	2.952	3.085	3.196	**3.294**
Operation and maintenance costs	$/kW/a	110	115	123	128	133	**137**

shown in FIGURE AF1. Generation costs today are around 8 to 26 $cents/kWh for the most important technologies, with the exception of photovoltaics. In the long term, costs are expected to converge at around 5-12 $cents/kWh. These estimates depend on site-specific conditions such as the local wind regime or solar irradiation, the availability of biomass at reasonable prices or the credit granted for heat supply in the case of combined heat and power generation.

4 ~ COST CURVES: DEFINING THE ORDER OF INVESTMENTS (ÜRGE VORSATZ, 2010)

While energy scenarios play an increasing role within the global, regional and national energy and climate debate, the different ways of setting up scenarios are under discussion. In principle there are 2 different types of scenarios: "Top-down" and "Bottom up" calculated energy scenarios.

Top-down scenarios are mostly cost driven, the cost projections for each technology, fuel costs and CO2 costs have a huge influence for the projected energy mix in the future as the model usually optimizes the mix in the basis of cheapest energy generation. A low cost projection for e.g. nuclear energy or the coal price will result in a large share of nuclear and coal power plants in the electricity generation of the future. However those models are often not very technology specific and in same cases there is not even a distinction between two very different solar electricity technologies to concentrated solar power (CSP) and photovoltaic (pv) as both technologies have very different capacities factors, costs and technical parameters. While "bottom up" scenario are technology driven and have therefore a very detailed breakdown of different technologies and can model energy system more exact. On the downside those models are not cost specific and they do not optimize the economic side of a future energy system. In the past years, both models are moving towards each other. While "top-down" scenarios have a greater level of technical details, bottom up scenarios include more and more economic parameters. The IEA World Energy Outlook – which is the reference scenario for both energy [r]evolution scenarios are in principle bottom up models, but with a greater level of cost assumptions. The section provides an overview about the resulting cost curves of all three scenarios. As "cost curves" do play an increasing role in the energy and climate debate.

GLOBAL RENEWABLE ELECTRICITY SUPPLY CURVES

FIGURE 1 shows the global renewable electricity supply curve for 4 scenarios: IEA WEO[1] (2009), ETP (2010), Greenpeace Energy Revolution (ER) and Greenpeace Advanced Energy Revolution (AER). For the ER and AER scenarios potentials are projected both for 2030 and 2050, while unfortunately no such forecasts were available for the IEA scenarios for 2050. The figures attest the importance of long-term frameworks for renewable energy. Potentials at the same costs more than double between 2030 and 2050 (please note that presently existing capacity is included in these potentials, with hydropower separated into "new hydro" and existing "hydro"). The IEA scenarios find significantly lower potentials at equal cost levels than the ER ones. Both IEA and the ER scenarios find wind as having a large potential at very competitive costs. In the ER scenarios this is followed by biomass and then PV in 2030, while PV becomes cheaper by 2050 than biomass. IEA scenarios project very low costs for CSP, lower than for wind, however, this technology is not expected to add a significant power production capacity to global electricity generation. Similarly, they also project app. half the cost for geothermal power for 2030 as the ER scenarios, however, they see very little potential for this technology; while ER scenarios project fairly large potentials at the highest (ER) or second highest (AER) cost levels from among the technologies. Ocean energy is expected to play a small role, except in the AER scenario, even if its costs are projected to be under that of several renewable electricity generation technologies.

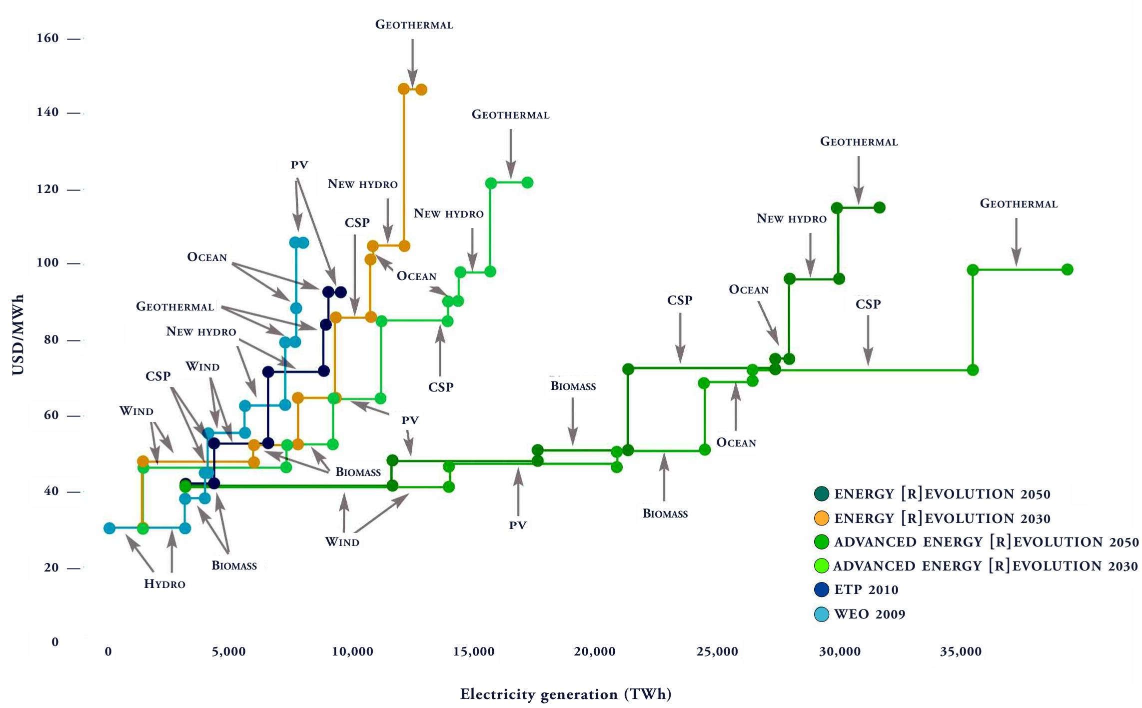


FIGURE 1 ~ **RENEWABLE ENERGY SUPPLY CURVES FOR THE ENERGY [R]EVOLUTION SCENARIO**

5 ~ SHIFTING TOWARDS RENEWABLES: A SUSTAINABLE GLOBAL ENERGY SUPPLY PERSPECTIVE

Worldwide renewable energy resources several times exceed current energy demand, the availability of renewable energy sources however differ between world regions. We use information on renewable energy potentials by world region and technology from (REN21 2008; Hoogwijk and Graus, 2008) as a basis for developing a renewable energy oriented supply scenario. As a response to the controversial discussion on the availability of biomass resources, a study on the global potential for sustainable biomass was commissioned as part of the Energy [R]evolution 2008 project (Seidenberger et al., 2008). The potential for energy crops strongly depends on food supply patterns and assumptions on agricultural production. Results for global biomass potentials from energy crops in 2050 range from 97 EJ in a business-as-usual scenario to only 6 EJ in a scenario which assumes no forest clearing, reduced use of fallow areas for agriculture, and expanded ecological protection areas. The global potential for biomass residues is estimated to be 88 EJ in 2050. With a biomass consumption of 88.7 EJ in 2050 the Energy [R]evolution scenario complies with the most stringent requirements towards sustainable biomass use.

ASSUMED GROWTH RATES IN DIFFERENT SCENARIOS

The Energy [R]evolution scenario is a "bottom-up" (technology driven) scenario and the assumed growth rates for renewable energy technology deployment are important drivers (Neij, L., 2008). Around the world, however, energy modelling scenario tools are under constant development and in the future both approaches are likely to merge into one, with detailed tools employing both a high level of technical detail and economic optimisation. The Energy [R]evolution scenario uses a "classical" bottom-up model which has been constantly developed, and now includes calculations covering both the investment pathway and the employment effect.

6 ~ KEY RESULTS

Today, renewable energy sources account for 13% of the world's primary energy demand. Biomass, which is mostly used in the heat sector, is the main source. The share of renewable energies for electricity generation is 18%, while their contribution to heat supply is around 24%, to a large extent accounted for by traditional uses such as collected firewood. About 80% of the primary energy supply today still comes from fossil fuels. Both Energy [R]evolution scenarios describe development pathways which turn the present situation into a sustainable energy supply, with the advanced version achieving the urgently needed CO_2 reduction target more than a decade earlier than the basic scenario. The following summary shows the results of the advanced Energy [R]evolution scenario, which will be achieved through the following measures:

— Exploitation of existing large energy efficiency potentials will ensure that final energy demand increases only slightly - from the current 305,095 PJ/a (2007) to 340,933 PJ/a in 2050, compared to 531,485 PJ/a in the Reference scenario. This dramatic reduction is a crucial prerequisite for achieving a

	Energy Parameter									
	Generation [TWh/a]							Annual Market Volume [GW/a]		
	> 600 ppm IEA WEO 2008	Reference	E[R]	advanced E[R]	Reference	E[R]	advanced E[R]	Reference	E[R]	advanced E[R]
2020	27708	27248	25851	25919						
2030	33265	34307	30133	30901						
2050	50606	46542	37993	43922						
PV 2020	68	108	437	594	17%	37%	42%	5	26	36
PV 2030	120	281	1481	1953	11%	15%	14%	18	91	124
PV 2050	213	640	4597	6846	10%	13%	15%	40	141	211
CSP2020	26	38	321	689	17%	49%	62%	1	5	12
CSP2030	54	121	1447	2734	14%	18%	17%	2	24	45
CSP2050	95	254	5917	9012	9%	17%	14%	4	44	66
Wind										
on+offshore2020	887	1009	2168	2849	12%	22%	26%	26	74	101
on+offshore2030	1260	1536	4539	5872	5%	9%	8%	60	178	229
on+offshore2050	1736	2516	8474	10841	6%	7%	7%	47	158	202
Geothermal										
for power generation										
2020	119	117	235	367	6%	14%	20%	1	2	4
2030	158	168	502	1275	4%	9%	15%	2	7	18
2050	229	265	1009	2968	5%	8%	10%	2	7	21
heat & power										
2010	2									
2020	6	6	65	66	13%	47%	47%	0	1	1
2030	9	9	192	251	5%	13%	16%	0	3	5
2050	17	19	719	1263	9%	16%	20%	0	6	11
bioenergy										
for power generation										
2020	324	337	373	392	8%	9%	10%	3	4	4
2030	474	552	456	481	6%	2%	2%	10	8	8
2050	650	994	717	580	7%	5%	2%	6	5	4
heat & power										
2020	272	186	739	742	2%	19%	19%	1	13	13
2030	367	287	1402	1424	5%	7%	8%	6	26	27
2050	613	483	3013	2991	6%	9%	9%	4	26	25
ocean										
2020	6	3	53	119	15%	55%	70%	0	2	4
2030	12	11	128	420	13%	10%	15%	0	3	12
2050	28	25	678	1943	10%	20%	19%	0	10	27
hydro										
2020	4164	4027	4029	4059	2%	2%	2%	20	20	21
2030	4833	4679	4370	4416	2%	1%	1%	135	126	127
2050	6027	5963	5056	5108	3%	2%	2%	78	66	67

TABLE 4 ~ **NEEDED RENEWABLE INDUSTRY DEVELOPMENT UNDER THREE DIFFERENT SCENARIOS**

significant share of renewable energy sources in the overall energy supply system, compensating for the phasing out of nuclear energy and reducing the consumption of fossil fuels.

— More electric drives are used in the transport sector and hydrogen produced by electrolysis from excess renewable electricity plays a much bigger role in the advanced than in the basic scenario. After 2020, the final energy share of electric vehicles on the road increases to 4% and by 2050 to over 50%. More public transport systems also use electricity, as well as there being a greater shift in transporting freight from road to rail.

— The increased use of combined heat and power generation (CHP) also improves the supply system's energy conversion efficiency, increasingly using natural gas and biomass. In the long term, the decreasing demand for heat and the large potential for producing heat directly from renewable energy sources limits the further expansion of CHP.

— The electricity sector will be the pioneer of renewable energy utilisation. By 2050, around 95% of electricity will be produced from renewable sources. A capacity of 14,045 GW will produce 43,922 TWh/a renewable electricity in 2050. A significant share of the fluctuating power generation from wind and solar photovoltaic will be used to supply electricity to vehicle batteries and produce hydrogen as a secondary fuel in transport and industry. By using load management strategies, excess electricity generation will be reduced and more balancing power made available.

— In the heat supply sector, the contribution of renewables will increase to 91% by 2050. Fossil fuels will be increasingly replaced by more efficient modern technologies, in particular biomass, solar collectors and geothermal. Geothermal heat pumps and, in the world's sunbelt regions, concentrating solar power, will play a growing part in industrial heat production.

— In the transport sector the existing large efficiency potentials will be exploited by a modal shift from road to rail and by using much lighter and smaller vehicles. As biomass is mainly committed to stationary applications, the production of bio fuels is limited by the availability of sustainable raw materials. Electric vehicles, powered by renewable energy sources, will play an increasingly important role from 2020 onwards.

— By 2050, 80% of primary energy demand will be covered by renewable energy sources.

To achieve an economically attractive growth of renewable energy sources, a balanced and timely mobilisation of all technologies is of great importance. Such mobilisation depends on technical potentials, actual costs, cost reduction potentials and technical maturity. Climate infrastructure, such as district heating systems, smart grids and super-grids for renewable power generation, as well as more R&D into storage technologies for electricity, are all vital if this scenario is to be turned into reality. The successful implementation of smart grids is vital for the advanced Energy [R]evolution from 2020 onwards.

It is also important to highlight that in the advanced Energy [R]evolution scenario the majority of remaining coal power plants – which will be replaced 20 years before the end of their technical lifetime – are in China and India. This means that in practice all coal power plants built between 2005 and 2020 will be replaced by renewable energy sources from 2040 onwards. To support the building of capacity in developing countries significant new public financing, especially from industrialised countries, will be needed. It is vital that specific funding mechanisms such as the "Greenhouse Development Rights" (GDR) and "Feed-in tariff" schemes are developed under the international climate negotiations that can assist the transfer of financial support to climate change mitigation, including technology transfer.

FUTURE COSTS

Renewable energy will initially cost more to implement than existing fuels. The slightly higher electricity generation costs under the advanced Energy [R]evolution scenario will be compensated for, however, by reduced demand for fuels in other sectors such as heating and transport. Assuming average costs of 3 cents/kWh for implementing energy efficiency measures, the additional cost for electricity supply under the advanced Energy [R]evolution scenario will amount to a maximum of $31 billion/a in 2020. These additional costs, which represent society's investment in an environmentally benign, safe and economic energy supply, continue to decrease after 2020. By 2050 the annual costs of electricity supply will be $2,700 billion/a below those in the Reference scenario.

It is assumed that average crude oil prices will increase from $97 per barrel in 2008 to $130 per barrel in 2020, and continue to rise to $150 per barrel in 2050. Natural gas import prices are expected to increase by a factor of four between 2008 and 2050, while coal prices will continue to rise, reaching $172 per tonne in 2050. A CO2 'price adder' is applied, which rises from $20 per ton of CO2 in 2020 to $50 per ton in 2050.

FUTURE INVESTMENT

It would require until 2030 $17.9 trillion in global investment for the advanced Energy [R]evolution scenario to become reality - approximately 60% higher than in the Reference scenario ($11.2 trillion). Under the Reference version, the levels of investment in renewable energy and fossil fuels are almost equal – about $5 trillion each – up to 2030. Under the advanced scenario, however, the world shifts about 80% of investment towards renewables; by 2030 the fossil fuel share of power sector investment would be focused mainly on combined heat and power and efficient gas-fired power plants. The average annual investment in the power sector under the advanced Energy [R]evolution scenario between 2007 and 2030 would be approximately $782 billion.

Because renewable energy has no fuel costs, however, the fuel cost savings in the advanced Energy [R]evolution scenario reach a total of $6.5 trillion, or $282 billion per year until 2030 and a total of $41.5 trillion, or an average of $964 billion per year until 2050.

FUTURE GLOBAL EMPLOYMENT

Worldwide, we would see more direct jobs created in the energy sector if we shifted to either of the Energy [R]evolution scenarios.

— By 2015 global power supply sector jobs in the Energy [R]evolution scenario are estimated to reach about 11.1 million, 3.1 million more than in the Reference scenario. The advanced version will lead to 12.5 million jobs by 2015.

— By 2020 over 6.5 million jobs in the renewables sector would be created due a much faster uptake of renewables, three-times more than today. The advanced version will lead to about one million jobs more than the basic Energy [R]evolution, due a much faster uptake of renewables.

— By 2030 the Energy [R]evolution scenario achieves about 10.6 million jobs, about two million more than the Reference scenario. Approximately 2 million new jobs are created between 2020 and 2030, twice as much as in the Reference case. The advanced scenario will lead to 12 million jobs, that is 8.5 million in the renewables sector alone. Without this fast growth in the renewable sector global power jobs will be a mere 2.4 million. Thus by implementing the E[R] there will be 3.2 million or over 33% more jobs by 2030 in the global power supply sector.

DEVELOPMENT OF CO2 EMISSIONS

While CO2 emissions worldwide will increase by more than 60% under the Reference scenario up to 2050, and are thus far removed from a sustainable development path, under the advanced Energy [R]evolution scenario they will decrease from 28,400 million tonnes in 2007 (including international bunkers) to 3,700 in 2050, 82% below 1990 levels. Annual per capita emissions will drop from 4.1 tonnes/capita to 0.4 t/capita. In spite of the phasing

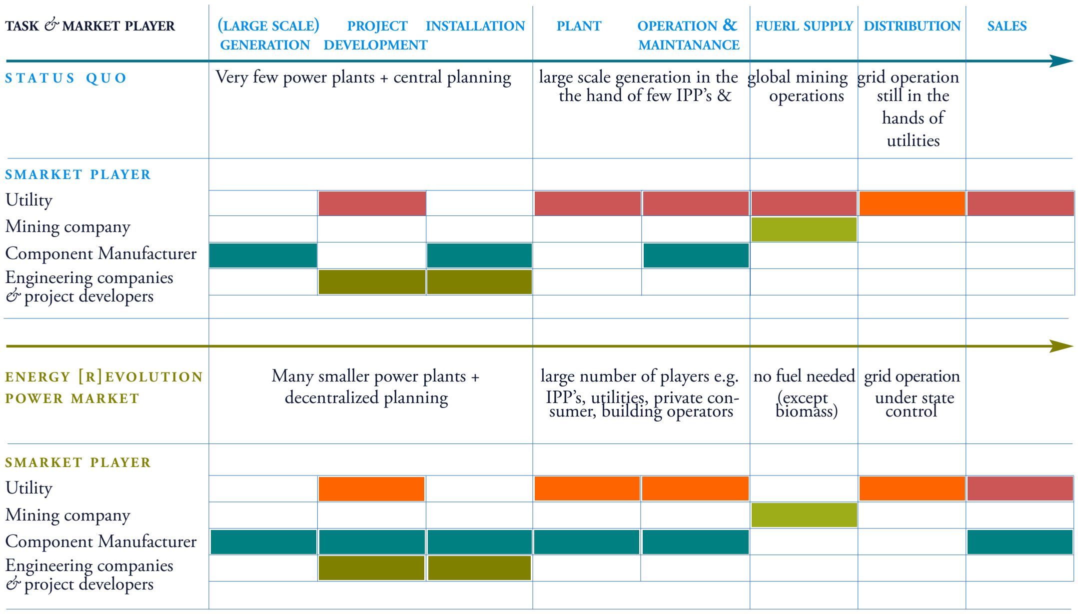


FIGURE 2 ~ VALUE CHAIN POWER MARKET TODAY AND UNDER THE ENERGY [R]EVOLUTION MODEL

out of nuclear energy and a growing electricity demand, CO_2 emissions will decrease enormously in the electricity sector. In the long run efficiency gains and the increased use of renewable electric vehicles, as well as a sharp expansion in public transport, will even reduce CO_2 emissions in the transport sector. With a share of 42% of total emissions in 2050, the transport sector will reduce significantly but remain the largest source of CO_2 emissions – followed by industry and power generation.

CHALLENGING THE BUSINESS MODEL OF TODAY UTILITIES

The Energy [R]evolution scenario will also result in a dramatic change in the business model of energy companies, utilities, fuel suppliers and the manufacturers of energy technologies. Decentralised energy generation and large solar or offshore wind arrays which operate in remote areas, without the need for any fuel, will have a profound impact on the way utilities operate in 2020 and beyond. While today the entire power supply value chain is broken down into clearly defined players, a global renewable power supply will inevitably change this division of roles and responsibilities. The following table provides an overview of today's value chain and how it would change in a revolutionised energy mix. While today a relatively small number of power plants, owned and operated by utilities or their subsidiaries, are needed to generate the required electricity, the Energy [R]evolution scenario projects a future share of around 60 to 70% of small but numerous decentralised power plants performing the same task. Ownership will therefore shift towards more private investors and away from centralised utilities. In turn, the value chain for power companies will shift towards project development, equipment manufacturing and operation and maintenance.

7 ~ CONCLUSIONS

Business-as-usual is clearly not an option for future generations, as this would have dramatic consequences for the environment, the economy and human society. The Energy [R]evolution scenarios show that options for change are at hand. Renewable energies can play a leading role in the world's energy future. Towards the mid of the century, renewable energy can provide close to 90% of the world's final energy needs, at the same time ensuring the continuous improvement of global living conditions, in particular in developing regions. In the days of a global financial and economic crisis, scenario results offer a positive message: investment in innovative renewable energy technologies contributes to economic growth, to the creation of jobs, and in the medium to long term helps to reduce the costs of global energy supply. By moving towards renewable energies, forward-thinking governments can act now to increase employment and investment opportunities.

There is no doubt that a global CO_2 emission trading system will be a key element in the portfolio of policy measures that is required to ensure compliance with climate protection targets. However, while it will take time until a difficult international negotiation process will finally succeed in establishing a global CO_2 trading system, we know from the IPCC 4th Assessment Report that we need urgent action now to curb CO_2 emissions. Complementary policy measures like feed-in tariffs for renewable energies have proved to be cost-effective in many countries, and are easy to implement on a national level. Facing the challenge ahead, there is no time to loose.

[1] Please note that the only investment cost data were available for IEA scenarios, therefore the other cost components, such as fixed and variable capital and generation costs, including OM, have been taken from the ER data.

TABLE A1 ~ **GLOBAL FINAL ENERGY DEMAND IN PJ/A**

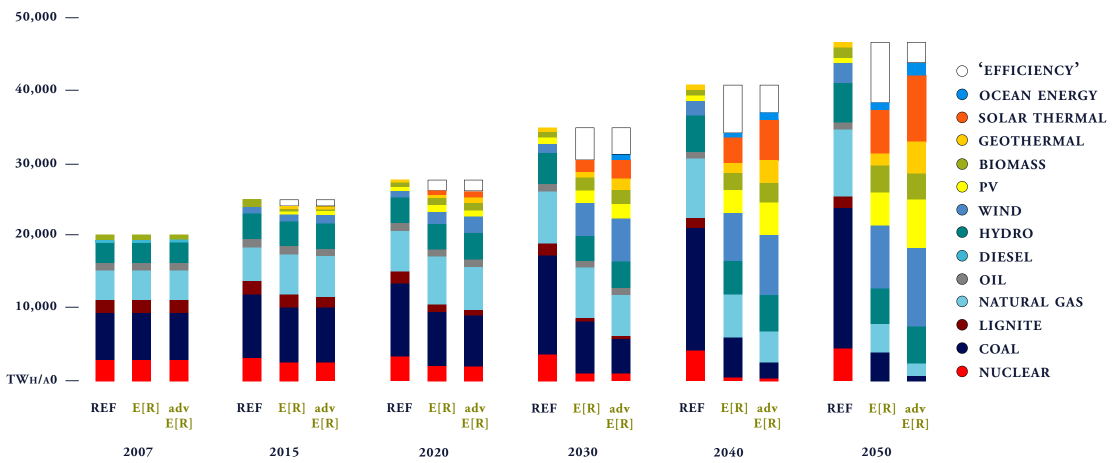
PJ/a	2007	2015	2020	2030	2040	2050
TOTAL **(incl. non-energy use)**	**337329**	**364357**	**374301**	**381812**	**377670**	**368650**
TOTAL ENERGY USE	**305093**	**329380**	**338056**	**343263**	**337271**	**326476**
TRANSPORT	**82068**	**87277**	**88691**	**86355**	**78012**	**69467**
- Oil products	76535	78901	76682	62767	41671	18448
- Natural gas	3131	3327	3253	2878	2130	1424
- Biofuels	1429	3258	4832	8062	9000	9723
- Electricity	973	1772	3574	11888	23420	36354
RES electricity	*171*	*401*	*1321*	*7692*	*19531*	*34613*
- Hydrogen	0	18	349	760	1791	3517
RES SHARE TRANSPORT	**1,9%**	**4,2%**	**7,3%**	**19,1%**	**38,9%**	**68,9%**
INDUSTRY	**99249**	**112145**	**115603**	**118509**	**118870**	**115865**
- Electricity	24995	31759	33787	36531	38720	39770
RES electricity	*4627*	*7622*	*12038*	*20944*	*30606*	*37202*
- District heat	9424	10605	12347	15249	19596	23718
RES district heat	*560*	*2213*	*4542*	*8800*	*15123*	*21468*
- Coal	19546	21902	20114	16417	6334	515
- Oil products	13517	12407	9889	6084	2802	815
- Gas	23872	25277	25926	24663	18398	6025
- Solar	5	741	2182	5518	12048	17457
- Biomass and waste	7878	8991	10042	11197	12252	12564
- Geothermal	12	462	1315	2850	7743	11330
- Hydrogen	0	0	0	0	976	3670
RES SHARE INDUSTRY	**13,2%**	**17,9%**	**26,1%**	**41,6%**	**65,4%**	**86,3%**
OTHER SECTORS	123776	129959	133763	138399	140389	141145
- Electricity	33253	37880	39973	44424	48406	52551
RES electricity	5842	9618	16114	27991	39913	50000
- District heat	6546	7968	9770	12740	16136	18145
RES district heat	439	1701	3610	7160	12504	16629
- Coal	4535	4007	3146	2658	978	23
- Oil products	19059	17886	15015	8687	4329	1090
- Gas	25970	24768	24429	19529	11441	2865
- Solar	378	1380	3834	11373	18762	26992
- Biomass and waste	33884	35345	36084	35758	33587	28815
- Geothermal	152	725	1513	3230	6750	10665
RES SHARE OTHER SECTORS	**32,9%**	**37,5%**	**45,7%**	**61,8%**	**79,4%**	**94,3%**
TOTAL RES	**55376**	**72462**	**97605**	**151116**	**220158**	**284295**
RES SHARE	**18,2%**	**22,0%**	**28,9%**	**44,0%**	**65,3%**	**87,1%**
NON ENERGY USE	**32236**	**34977**	**36245**	**38549**	**40398**	**42174**
- Oil	24832	26267	27026	28444	29627	30761
- Gas	6084	6901	7289	7951	8400	8817
- Coal	1320	1808	1930	2154	2371	2595

TABLE A2 ~ **PRIMARY ENERGY DEMAND UNDER THE ADVANCED ENERGY [R]EVOLUTION PER REGION**

PRIMARY ENERGY PJ/A	2007	2015	2020	2030	2040	2050
OECD	230.864	216.760	202.070	180.841	157.571	138.28
NA	115.751	108.607	101.969	90.853	81.332	70.227
Europe	77.525	72.095	66.504	59.077	50.784	46.754
Pacific	37.588	36.059	33.596	30.911	25.455	21.299
Rest	259.335	302.512	314.672	319.802	321.902	327.715
WORLD	**490199**	**519272**	**516742**	**500642**	**479473**	**465995**

TABLE A3 ~ **GDP DEVELOPMENT IN ALL THREE SCENARIOS**

	2007-2015	2015-2030	2030-2040	2040-2050	2007-2050
World	3,30%	3,00%	2,70%	2,44%	**3,39%**
OECD Europe	1,00%	1,80%	1,30%	1,10%	**1,37%**
OECD North America	1,80%	2,27%	1,55%	1,45%	**1,77%**
OECD Pacific	1,10%	1,23%	1,33%	1,40%	**1,27%**
Transition Economies	4,60%	3,77%	2,60%	2,54%	**3,38%**
India	7,00%	5,90%	3,20%	2,50%	**4,65%**
China	8,80%	4,40%	3,20%	2,55%	**4,74%**
Other Developing Asia	7,20%	4,60%	2,50%	2,20%	**4,13%**
Latin America	3,10%	2,50%	2,60%	2,40%	**2,65%**
Africa	4,70%	3,10%	3,40%	3,40%	**3,65%**
Middle East	4,50%	4,00%	2,30%	2,00%	**3,20%**



REFERENCE, ENERGY [R]EVOLUTION AND ADVANCED ENERGY [R]EVOLUTION ["EFFICIENCY"=REDUCTION COMPARED TO THE REFERENCE SCENARIO]

FIGURE AF1 ~ GLOBAL DEVELOPMENT OF ELECTRICITY GENERATION STRUCTURE UNDER THREE SCENARIOS

TABLL A4 ~ GLOBAL: PROJECTION OF RENEWABLE ELECTRYCITY GENERATION CAPACITY UNDER BOTH ENERGY [R]EVOLUTION SCENARIOS

IN GV

		2007	2020	2030	2040	2050
HYDRO	E[R]	922	1,206	1,307	1,387	1,438
	advanced E[R]	922	1,212	1,316	1,406	1,451
BIOMASS	E[R]	46	212	336	500	652
	advanced E[R]	46	214	343	501	621
WIND	E[R]	95	818	1,733	2,409	2,943
	advanced E[R]	95	1,140	2,241	3,054	3,754
GEOTHERMAL	E[R]	11	49	108	196	279
	advanced E[R]	46	69	238	469	693
PV	E[R]	6	335	1,036	1,915	2,968
	advanced E[R]	6	439	1,330	2,959	4,318
CSP	E[R]	0	105	324	647	1,002
	advanced E[R]	0	225	605	1,173	1,643
OCEAN ENERGY	E[R]	0	29	73	168	303
	advanced E[R]	0	58	180	425	748
CSP	**E[R]**	**1,080**	**2,813**	**4,917**	**7,224**	**9,585**
	advanced E[R]	**1,080**	**3,359**	**6,252**	**9,987**	**13,229**

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