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Energy sector in transformation, trends and prospects

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Abstract

The global energy sector currently is in turmoil because of different and often conflicting drivers and reasons: growing energy demand from emerging economy countries, the global economic crises, climate change policies, peak oil phenomena, the sudden increase of shale oil and shale gas production in the United States, geopolitical tensions, the demise of nuclear energy and last but not least the plummeting costs of renewable energy technologies. Global energy scenarios from established organisations like the International Energy Agency (IEA), World Energy Council and the big oil firms however give comparable expectations about probable future energy systems. They have one thing in common: they will all lead to a higher global temperature increase than the 2 degrees Celsius seen as the acceptable limit by climate scientists and as a consequence are not environmentally sustainable. Normative scenarios from the IEA, but also from NGOs such as Greenpeace, that take the CO_2-emissions reductions needed as a starting point, show that a clean energy future that fulfils expected global energy demand is technically and economically possible. However, except for power production from renewables, the development of the clean energy technologies needed is not (yet) on track. Starting from this observation the author develops guidelines for the development of a clean energy future which basically consists of a combination of an accelerated direct and indirect electrification of energy demand combined with an accelerated shift to power production from renewables against a background of continuing energy efficiency improvements, including efficient use of waste heat flows. Also the main consequences and challenges of this development are discussed, including the development needed of new control and management strategies which will need smart ICT solutions

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Keywords: energy scenarios; renewable energy; climate change; peak oil; shale gas; shale oil; electrification; learning curve; wind energy; solar PV; energy efficiency; sustainability; global energy demand

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1. Introduction: energy sector in turmoil

1.1. Incumbent energy players in heavy weather

In October 2013 the CEO's of 10 of the biggest energy companies in Europe, fierce competitors in many European countries, gathered together in Brussels to jointly plea for support of conventional power plants and against subsidies for renewable energy in Europe, arguing that their business would otherwise become uneconomical[1]. Some critics of this event said it seemed a little bit like Kodak pleating against the introduction of digital photography because otherwise their business model would break down. However, others would argue that the utility companies were right in saying that the energy market was distorted by government support leading to unnecessary overcapacity in the electricity industry. An article in The Economist[2] pointed out that the utility sector in Europe had lost half a trillion Euro in capitalization value in 5 years. Whatever one thinks of the action of the big utility companies, the fact that this event took place makes it clear that change is happening in the energy sector and that at least some of the incumbent players have difficulties dealing with it.

In December 2014 EON one of the biggest European energy utilities took the next step in its strategic analysis and announced a dramatic measure[3]: from now it will focus only on renewables, smart grids and energy services to the customer. It will divest from its current fossil fuel and nuclear central power station assets, put them in a separate company and sell them off. This dramatic decision was taken after heavy losses that EON and other big utilities in Germany and Europe have incurred during the last few years. The nuclear phase-out policy and the subsidy of renewables, in which the traditional utilities have not been heavily involved in up to now, were pointed out as the main causes of these losses.

1.2. Trends and issues affecting the global energy sector

Since the summer of 2014, when oil prices were still at a historically relatively high price of above 100 dollar/barrel, these prices have plummeted to less than half of that. The explanation is that Saudi-Arabia wants to maintain its market share and is not willing to reduce its production output anymore which would lead to losing market share. The main trend behind this is the upcoming North American production from shale oil, gas and tar sands[4]. Investments in shale oil and shale gas have been made massively in the last years. This has been made possible by technology improvements in horizontal drilling and rock fracturing ("fracking") and the investments were made in the expectation of continuous high oil prices and increasing global demand. However, global demand is not increasing as fast as expected, partly due to the continuing global economic downturn, partly due to energy efficiency measures that are starting to affect global energy demand. Many of these shale oil and gas investments now turn out to be uneconomical and new investments in rigs are delayed and existing rigs are shutting down. This might lead to underinvestment in oil and gas exploration in the coming years, possibly leading to a sharp increase in prices later in the decade.

Climate change and climate change policy have an enormous effect on the energy sector, although not always in the way it is expected. That climate change is real is not contested anymore, that human activity is the cause of that is supported by a large majority of climate scientists[5]. The trend in CO_2 emissions, seen as the main cause of climate change, has been accelerating during the last decade, mainly due to Asia's (and in particular China's) economic upswing which has been fueled mainly by domestic coal, the most CO_2-intensive fuel. Climate change policies have not been enough to mitigate these emissions, but have been and are being implemented in more and more countries. Europe has been at the forefront of these policies. Since the late 1990's, targets have been set for renewable energy, energy conservation and greenhouse gas emission reduction to be fulfilled by 2010 with new additional targets for 2020 and now also for 2030. The flagship policy instrument for this, a cap-and-trade CO_2 emission permit market, has not turned out to work very well. Because of lower-than-expected energy demand, CO_2 emissions in Europe have been much lower than expected (which might be regarded as a good thing in itself). As the total annual amount of CO_2 emission permits were determined before the crisis based on the expected higher energy demand, there is now an oversupply of emission permits leading to reduced permits prices that in turn disrupt the signal to divert from coal power plants (with a very high level of CO_2 emissions per unit of energy) in favor of natural gas power plants (with CO_2 emissions being about $1/3^{rd}$ of coal power plants) in Europe. Support for renewable energy in the Member States has been another policy consequence of climate change policy and technologies like wind and solar have been brought into the market mainly by different kinds of governmental support systems.

New renewable technologies (especially wind and solar) have undergone substantial technological learning effects on a global level, to the point that in some markets and market segments in Europe and globally the generation cost of electricity from wind and solar has become competitive with new conventional power plants or electricity purchase from the grid. However, the subsidy systems do often not adapt fast enough. This has led to faster implementations than expected, has resulted in budget overspending and led to stop-and-go renewable energy policies. The incumbent players are not benefitting from this. They are not the main investors in the new renewable energy technologies but have left that to smaller players, down to the point of individuals and local energy cooperatives.

A slow but steady decrease of the use of nuclear power in the global energy production can be observed. In about 10 years its relative contribution to the European power generation has been reduced from 33% in 1997 to 27% in 2011. The global share to primary energy production has come down from its top of about 6% in 2007 to 5% today. Since the Fukushima incident in March 2011, nuclear phase out policies that had been put to question in a few European countries have now been reconfirmed. Even though in Belgium and Japan most recent policies support reopening or life extension of existing plants, this appears hard to implement because of safety concerns for the older plants. The average age of the total nuclear fleet is 28 years old[6], meaning that many plants are near the end of their economic and technological lifetime with life extension decisions becoming more and more difficult because of the enhanced safety requirements. In addition, the economics of new nuclear power plants seem to be far less advantageous than initially projected a few years ago. Two nuclear power plants that are being built (one in France and one in Finland) have substantial construction time and budget overruns. The UK wants to support nuclear for climate policy reasons (as nuclear does not emit CO_2), investing more capital for a longer time period than the support Germany provides to solar and wind energy, indicating that renewables are a lower-cost option for clean energy generation than new nuclear in many places in the world. New nuclear power plants are built in countries with regulated markets and strong government support (China, Russia, India), but it is hard to see how the share of nuclear energy can climb above its record level of 6% in the coming decades.

Last but not least in this small overview of trends that affect the global energy system the geopolitical aspects of energy should not be underestimated. The dependence of Europe on Russian natural gas is a main example; on the other hand, the dependence of the Russian economy on fossil fuels makes it very vulnerable for oil and gas price decreases. Oil revenues, legal and illegal, play an important role in financing terrorist groups in the Middle East and Africa. Dependence on Middle Eastern oil is an important reason that democratic nations sometimes support totalitarian regimes that hardly respect human rights.

2. An analysis of the energy sector: present and future

To get a better understanding of the short-term symptoms we see of an energy sector in turmoil, a deeper analysis of the current situation and the trends is needed.

2.1. Current global energy use and production

There are several organisations and companies that regularly provide global energy scenarios. Among them the the International Energy Agency (IEA) the World Energy Council (WEC), the global oil companies Exxon, Shell and BP and NGOs such as Greenpeace. To start with it is helpful to see how large the current global Total Primary Energy Supply is and how large the shares of the different energy resources are (Table 1)[7].

Table 1. World Total Primary Energy Supply 2012

Energy Resource	Primary Energy Supply (EJ)	Relative share (%)
Coal	162	29,0%
Oil	176	31,4%
Natural Gas	119	21,3%
Nuclear	27	4,8%
Hydro	13	2,4%
Biofuels	56	10,0%
Other Renewables	6	1,1%
Total	560	100%

What can be observed from this table is that fossil fuels contribute 82% of our energy supply. Nuclear is at almost 5% and renewables provide 13,5%.

These statistics are somewhat deceptive in a certain way: for non-fuel renewables (hydro, solar, wind), the output in electricity production is taken as equal to the primary energy input, whereas for instance for nuclear energy the energy content of the nuclear fuel is taken as primary input. With an average efficiency of nuclear power plants of about 40% it can be seen that the actual electricity production from hydro was a little bit larger than the actual production of electricity from nuclear. In general primary energy supply statistics underestimate the contribution of non-fuel renewables. However, that being the case, it can be seen that the contribution of new renewable energy sources like solar and wind is still almost negligible.

If we look at the world Final Energy Consumption, the picture becomes a little bit different (Table 2)[7].

Table 2. World Total Final Energy Consumption 2012

Energy Carrier	Final Energy Consumption (EJ)	Relative share (%)
Oil	153	40,7%
Electricity	68	18,1%
Natural Gas	57	15,2%
Biofuels and waste	47	12,4%
Coal	38	10,1%
Heat and Other	13	3,5%
Total	376	100%

Final consumption of energy is dominated by oil, which is mainly related to the use of oil products in the transportation sector (cars, trucks, ships, airplanes). The direct use of coal and natural gas, for instance for heating and cooking or for industrial processes, is lower than the use of biofuels and waste. Electricity as an energy carrier counts for less than 20% of our final energy use. We can also see that final energy consumption is 560-376=184 EJ lower than the total primary energy supply. These losses in the energy value chain are mainly due to losses in electricity production.

As said before for non-fuel renewables such as hydro, wind and solar, the primary energy input is taken as equal to their output. A shift in electricity production to these non-fuel renewables would have as a statistical effect a reduction in total primary energy supply. Furthermore we know that most processes driven by electricity (e.g. heat pumps for heating or electric motors for transportation) have a much higher efficiency than technologies based on fossil fuels. So a further electrification of energy use in the heating and transport sector can also have a high beneficial effect on our primary energy supply needs.

2.2. Global Energy Scenarios

Shifting to electricity and renewables might have a beneficial effect on our primary energy needs, but on the other hand the world energy demand will increase enormously over the next decades. The Exxon Outlook for Energy[8] makes this very clear, as can be seen in the next table:

Table 3. Global primary energy needs forecast by Exxon Outlook for Energy 2015

Energy Resource	Primary Energy Supply 2010 (EJ)	Primary Energy Supply 2040 (EJ)
OECD-countries	244	234
Non-OECD-countries	310	522
Total	554	756

In this forecast an enormous amount of energy efficiency measures is already included. In the OECD countries, these will be enough to stabilize primary energy supply needs. But most of the growth will take place in the non-OECD countries. A quick assessment how much energy savings are assumed in this forecast leads to the following: Exxon assumes about 2.8% global GDP annual growth rate. Over a 30 year period this leads to a global GDP that is about 2.3 times the 2010 global GDP. Without any energy efficiency measures this would lead to a primary energy demand of 554*2.3=1274 EJ. The assumed energy savings are 1274-756 = 518 EJ, which is in the same order of magnitude as the current global total primary energy supply needs.

Exxon does expect that there is a large growth of renewables and that there is some shift to electricity use, but not to the extent that fossil fuel use will be reduced.

Table 4. Global primary energy needs per energy resource forecast by Exxon Outlook for Energy 2015

Energy Resource	Primary Energy Supply 2010 (EJ)	Primary Energy Supply 2040 (EJ)
Oil	178	228
Natural Gas	116	189
Coal	135	138
Nuclear	29	56
Biomass and waste	49	56
Hydro	12	20
Other renewables	7	29
Total	555	755

Total use of fossil fuels is expected to be around 550 EJ which is 20% more than today. Scenarios of other global oil companies[9,10], the World Energy Council[11] and the Reference Scenario and New Policies Scenario of the International Energy Agency[12] come to comparable results.

An underlying assumption is that there will be no ‘peak oil’ moment on the supply side the coming decades. Peak oil is something different from exhaustion of fossil fuel reserves. Peak oil refers to the fact that every oil well has a peak in its production after a certain time and after that it is still producing but at a lower rate. As the number of newly discovered oil wells slows down this peak oil effect would also become visible for the total global oil production. For conventional oil production this has indeed happened in 2006[13]. But the main analysts believe that unconventional oil sources (shale oil, tar sands, deep ocean oil, arctic oil) will be able to fill the gap the coming decades[9, 10, 11,12]. There are some analysts who disagree with this view and predict an oil price shock in the next 5 to 10 years[14].

2.3. Mainstream global energy scenarios are all environmentally unsustainable

Whether or not fossil fuels will become scarce or not is maybe not the most relevant factor to worry about with regard to what seems as the most probable energy future. As pointed out by the International Energy Agency, none of the scenarios is compatible with the climate change target of keeping the rise of the average global temperature below 2 degrees Celsius. An increase in average global temperature of 2 degrees Celsius is seen as in line with a minimal risk on global climate disruption and as such functions as a reference for international climate policy. To achieve a reasonable chance that the temperature increase will stay below 2 degrees Celsius, the concentration of CO_2 in the atmosphere should stay below 450 parts per million (ppm). Currently the concentration is 400 ppm, but with future emissions it is certain it will increase further. To stay below 450 ppm emissions should stabilize very soon and then decrease to at least by 50% in 2040 and then further down to 0% during the rest of the century.

Table 5. CO_2 emissions in main and most probable energy scenarios compared to emission path needed

Scenario	Emissions 2010 (Gt CO_2)	Emissions 2020 (Gt CO_2)	Emissions 2025 (Gt CO_2)	Emissions 2030 (Gt CO_2	Emissions 2035 (Gt CO_2)	Emissions 2040 (Gt CO_2)
IEA ETP 2 Degrees (needed)	32	34	32	28	22	20
Exxon Outlook for Energy 2015	31		37			37
BP Energy Outlook 2015	31				41	
Shell Mountains Scenario	31	38		42		39
Shell Oceans Scenario	31	40		44		43
Shell Oceans Clean and Green	31	40		42		37
IEA WEO Reference	31					39
IEA WEO New Policies	31					37
WEC Jazz	31	36		41		45
WEC Symphony	31	32		30		27

The IEA 2 Degrees Scenario described in its bi-annual publication "Energy Technology Perspectives[15]" is a so-called 'normative' scenario. It takes the emission reductions needed as a boundary condition and then looks for ways to fulfill expected energy demand within these boundaries. It shows that a sustainable energy future is possible, but then several new technologies and increased energy policy measures have to be taken.

The other scenarios are expectations of probable futures. The table shows that all these scenarios do not fulfill the boundary condition of staying below 450 ppm CO_2 concentration in the atmosphere. In general they lead to an estimated rise in global temperatures between 4 and 6 degrees Celsius, with disastrous consequences implied for our society as a whole. Clearly the most probable energy scenarios are all not sustainable.

2.4. Most clean energy technologies not on track

According to the International Energy Agency[15] most clean energy technologies that are needed to get to the reduction of CO_2-emissions required are not on track with regard to their implementation and/or development. These clean energy technologies are:

- Clean coal technologies for power generation
- Carbon Capture and Storage
- Nuclear Energy
- Energy savings in buildings
- Energy Efficiency in industry
- Gas-fired power generation
- Biofuels
- Combined heat and power generation

- Energy-efficient transport
- Hybrid and Electric Vehicles
- Smart Grids
- Renewable Power generation

The only technologies that are (more than) on track is the last one: renewable power generation. However, this can only lead to the projected and needed growth if support policies are sustained and modernized. All the others are either not on track at all (biofuels, buildings, carbon capture and storage, clean coal and nuclear) or are in promising but still not sufficient development or implementation (industry, gas-fired power, smart grids, cogeneration, clean transport, hybrid and electric vehicles).

A scenario by Greenpeace[16] is focusing only on energy efficiency and renewable energies to reduce the projected business-as-usual primary energy need of about 750 EJ in 2040 to less than 200 EJ from fossil fuels (with a dominant share in this 200 PJ of natural gas). Also other 'normative' scenarios have been made that take the reduction of CO_2 emissions needed as a starting point. One extreme scenario study is a study made for the Belgian government with the research question whether a 100% renewable energy system for Belgium by 2050 is possible, what it would look like and what it would cost[17]. The outcome was that this is theoretically and technically possible, that the extra costs compared to a reference scenario would be between 2% and 4% of GDP, but that the realization would require very stringent and sometimes unconventional policy measures and system changes.

3. Guidelines for the development of a sustainable energy system

3.1. Focus on what goes well: renewable power production

Renewable energy includes large hydropower and biomass. The potential of hydropower has been largely exploited, although it could maybe double in the coming decades. In most energy scenarios this is already taken into account. Biomass use is already large and could increase further, but in that case several sustainability issues will have to be addressed. What still has a large potential are the Other Renewables, i.e. especially wind and solar energy. As can be seen from Table 1, their current contribution to the energy mix is about 6 EJ, or 1% of primary energy supply.

Wind and solar being so small, while at the same time growing so fast, relevant questions are:

- Are growth rates high enough to deliver a meaningful contribution to the global energy mix on time?
- Are costs coming down fast enough to make them affordable?
- Is their potential big enough to deliver the energy services needed?

If we take solar photovoltaic electricity production as an example, we see that the compound annual growth rate of this technology between 2000 (with 1,3 GW installed worldwide) and 2013 (with 138,8 GW installed worldwide) has been well above 40%. Also with every doubling, on average the price per W installed has come down with 20%-22%. If we assume these trends continue we can take as a rule of thumb that the installed capacity doubles every 2 years and the price will be cut in half every 5-6 years. If we take wind as another example we see that the growth rate between 1997 (7,6 GW) and 2014 (369 GW) has been about 25%-26%, which, as a rule of thumb comes down to a 1,5 times increase every 2 years. With an average cost reduction per kWh of 20% with every doubling of cumulative installed capacity, the price will be cut in half every 9-10 years.

If we implement these simple rules of thumb in a scenario starting in 2002 we get the outcome up till 2030 as shown in Table 6. We should note the following:

- This is a simple, exponential, trend extrapolation model. Such models over time will become unrealistic. Market saturation effects will bend this trend into an S-curve. Anyway, the analysis shows that towards 2040, even with saturation effects, wind, solar and other renewables can be the main source of power generation.
- The final outcomes for 2030 still lie well within the range of the physical potential. In the case of solar energy, the amount of solar energy falling on earth every year is about 5000 to 10000 more then we

need (or in other words: in about 1 hour the equivalent of the annual global energy consumption falls on the earth as solar energy).

- The exponential trend between 2002 and 2014 represents well the actual developments. In fact for solar PV (with an actual installed capacity of an estimated 185-190 GW at the end of 2014) it is even too pessimistic. The wind energy number matches well with realized installations.
- One should realize that still other renewable energy sources like hydro and geothermal can and will contribute to the power mix.
- As only a 'normal' 3% growth rate for electricity is taken as a reference for growth in electricity use, shares of above 100% indicate there is room for accelerated electrification of our energy system while being able to clean up the system at the same time.
- The transition from a marginal share (below 1-2%) to a substantial share (10% and above) is happening quickly and is happening now. In some countries faster than in others. This leads to distortion of energy markets and hits most the incumbent energy utilities that have not yet heavily invested in renewables themselves.
- Taking the inflation rate into account and applying the rule of thumb method for solar PV the costs have indeed come down from a nominal 6 Euro/W in 2002 to a nominal 1,3 Euro/W today which is well in the range of the rule of thumb. Further costs reductions along this trend can be expected making solar and wind the least expensive power generation options in the near future.

Table 6. Simplified trend extrapolation scenario to check whether solar and wind can deliver enough power on time

Year	Solar PV capacity (GW)	Wind energy capacity (GW)	Solar PV power production (TWh)	Wind power production (TWh)	Wind & Solar production (PWh)	Global power production (PWh)	Share of wind & solar (%)
2002	2	31	3	62	0,1	16	0%
2004	4	47	5	93	0,1	17	1%
2006	8	70	10	140	0,1	18	1%
2008	16	105	21	209	0,2	19	1%
2010	32	157	42	314	0,4	20	2%
2012	64	235	83	471	0,6	21	3%
2014	128	353	166	706	0,9	23	4%
2016	256	530	333	1059	1,4	24	6%
2018	512	794	666	1589	2,3	25	9%
2020	1024	1192	1331	2383	3,7	27	14%
2022	2048	1788	2662	3575	6,2	29	22%
2024	4096	2681	5325	5363	10,7	30	35%
2026	8192	4022	10650	8044	18,7	32	58%
2028	16384	6033	21299	12066	33,4	34	98%
2030	32768	9050	42598	18100	60,7	36	168%

3.2. Go for electrification of transport, heating and industrial processes

In the light of the analysis above it becomes clear that accelerated electrification of our energy use combined with an accelerated shift to renewables (in line with historical trends) is a very promising way to clean up the global energy system. Looking at the Exxon figures for 2040 a shift to non-fuel renewables alone would reduce 291 EJ primary energy needed close to the 117 EJ of electricity demand, meaning a primary energy supply need reduction of about 170 EJ. Suppose half of the 140 EJ needed for transport can be directly electrified with electric engines three times more efficient than today's combustion engines, then this leads to another 40 EJ primary energy reduction. A shift from natural gas or coal to electricity in the production refined materials such as steel will be possible based on clean renewable power generation.

For some uses, especially in the transport sector (long-haul trucks, shipping, aviation) some kind of fuel will be needed. This fuel can be made out of electricity (producing hydrogen and combining that with CO_2 captured from flue gases or from ambient air, so-called “power-to-gas” or “power-to-fuel” technologies) at moments when there is an oversupply of renewable electricity. In this way seasonal fluctuations of intermittent renewable energy production can be dealt with, while at the same time producing renewable fuels.

3.3. Stay focused on energy efficiency measures

The fact that technological solutions are possible on the supply side of the energy system does not reduce the need to stay focused on energy efficiency as well. As must be clear by now, the amount of investments needed to restructure and reorient the energy supply side of the sector is enormous and will only grow with additional energy demand. Therefore energy efficiency in buildings (insulation, glazing, controlled ventilation, energy efficient heating and cooling), industry (industrial heat pumps, application of best available technologies) and transport (higher efficiency engines for ships, airplanes etc.) remains critical for a transition to a cleaner energy system.

An important way to save primary energy is to use waste heat of industrial processes as a way to heat large part of the existing building stock. In combination with electric heat pumps they can minimize the need for liquid and gaseous energy carriers for heating and cooling.

4. New energy system, new challenges

4.1. Intermittency, flexibility and the distributed character: towards an ‘ internet of energy’

As wind and solar play an important role in the new upcoming energy system, the character of the whole system is changing. Instead of a system based on centralized control, a limited number of large power plants and characterized by mono-lateral flows of energy, information and money, it is becoming a system with many dispersed intermittent energy production resources, with a totally different ownership structure, characterized by bilateral flows of energy, money and information. Such a system is becoming more and more similar to the internet, with ‘uploading’ and ‘downloading’ of energy, ‘ energy routers’ and ‘energy buffers’. Because of the intermittent character of solar and wind (they produce according to the weather conditions, not according to an independent external demand for electricity) flexibility on the demand or supply side will get a market value (which can also be provided by energy storage). For instance electric vehicles will need to be charged intelligently and might even become able to feed energy back to the grid. Heat pumps coupled to heat buffers might start to operate when there is plenty of energy available and store the energy not needed right away in big buffers for later use. Aluminum factories will produce more when the sun shines or the wind blows and use the molten aluminum buffer in times of less supply.

In this internet of energy many control and information flow challenges will have to be overcome. A big role for ICT in these upcoming field of Intelligent Power Systems.

5. Conclusion

The global energy system is in turmoil nowadays. Many things happen at the same time. Some are relatively short-term, such as heavily fluctuating oil prices and failing CO_2 emission markets. Others are long-term and more predictable, such as the increasing global demand for energy services we can expect from the emerging economies in the world and the steadily falling costs for new renewable energy technologies. And in the background there is always the strategic and geopolitical character of energy, especially in the case of fossil fuels.

We see that most energy scenarios that forecast probable energy futures are all not sustainable from a climate change point of view. This is the case despite existing clean energy and CO_2-reduction policies. However, these policies have led to a steep learning curve for and uptake of upcoming renewables, mainly solar and wind. These no-fuel cost renewables are now disrupting the 'old world' of the classic energy utilities in the western world, some of which are heavily resisting and lobbying against policies promoting these renewables.

Many of the clean technologies, mainly those ones related to extending fossil fuel use, are not on track to meet the challenge of creating an affordable energy system that addresses the climate change issue. The fast cost reduction of new renewables for power production is an exception. This leads to a realistic possible future of a clean energy system that can address climate change. Guidelines for such a system are, apart from a constant focus needed on energy efficiency, a swift shift to power production from renewables and at the same time a quick electrification (direct or indirect) of our energy use.

The energy and power system will change and is already changing a lot. It is becoming more decentralized, dispersed and intermittent. Exchange of energy, information and money will become much more complex. ICT will have to play a major role in solving these issues.

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