Smart houses and regions as building blocks for 100% renewable energy globally

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Abstract

This paper gives evidence that in contrast to the old big and centralized approach with large power stations there is now a solution possible which starts bottom-up. Individual houses are no longer only consuming electricity but will also produce electricity with PV systems on their roof – they become pro-sumers. The same happens with multi-family houses, offices and SME's. Small battery systems increase significantly the self-consumption. Adjacent prosumers will be able to exchange power. Next level is the area of municipalities also integrating nearby wind farms and green-field PV plants to leverage the seasonal electricity production. Larger battery systems and power-to-gas facilities enable progressively the balanced supply and usage. Communication and exchange of electricity and gas between various municipalities will enable the 100% supply by renewable sources of the needed electricity, mobility (once electrified) and heat for the individual countries. Energy intensive industries will be located near to GW-scale off-shore wind and/or PV-farms.

1 Introduction

Only a few years ago it was difficult to imagine a world, powered 100% by renewables only – not only electricity, but all secondary energy needs, including transportation, heating and cooling as well as industry needs. Major reason for this was that the production cost for electricity from wind and solar was much too high and electricity storage not seen as an option at all. Only with large centralized solar concentrating systems together with hydrogen production (hydrogen economy) or a world-wide distribution system (using high voltage DC current) a renewably powered world was seen potentially possible in the long run.

Until today the energy world was top-down: few big and centralized power stations produce the base load power which is transported with a high-voltage grid network. Peak power stations provide the electricity needs for all consumers at any time. This situation is shown in the left graph of Fig. 1. With the rapidly declining cost per produced kWh from PV and wind, together with the push from the automotive sector for Li-ion batteries which also results in a quick reduction of electricity storage cost, there is now – including IoT - a new horizon opening how to serve man-kinds energy needs rather quickly. This enables a complete new situation: the consumers become also producers of energy and most of the needs can be served locally; centralized systems – e.g. large off-shore wind or big PV farms – are in minority. This is summarized in the right graph of Fig.1.

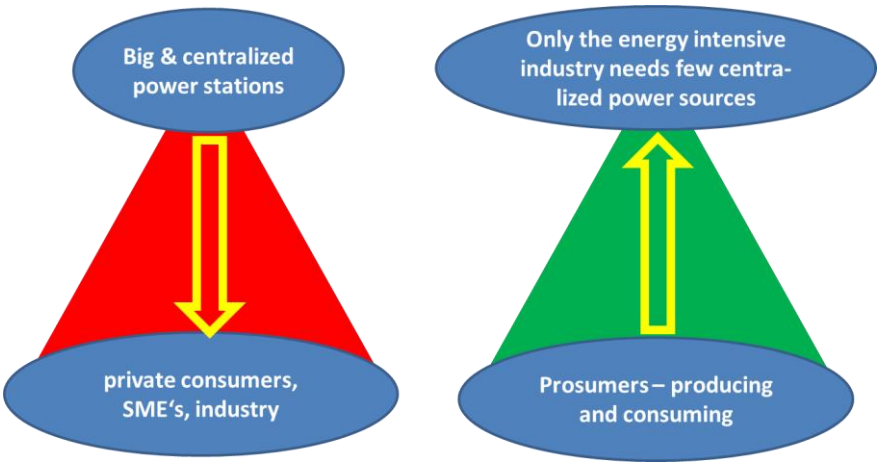

Fig. 1: Top-down (left) and bottom-up (right) energy world

2 Three building blocks

2.1 1st building block

Individual houses, offices and stores are seen as **the first building block**, where on-site as much as possible renewable energy is produced by PV and together with batteries (k-/MWh) self-consumption is as high as possible. With proper insulation and heat-pumps (also including thermal modules where appropriate) the heating and cooling energy needs are minimized. This situation is summarized in Fig. 2. The integration of a small battery increases significantly the self- consumption in individual homes from ~20% without up to 80% (if an electric car is integrated) on an annual basis. It is interesting to note that the battery not only shifts PV electricity from the afternoon to the evening hours, but also can shift cheap night electricity to the more expensive morning peaks as seen in Fig. 3.

Next step is the integration of adjacent buildings for exchanging energy. As the number of communicating buildings increases the self-consumption of the quartier is also increasing and always higher than the sum of the individual homes. This concept is already in place in Italy and Switzerland, many others have still bureaucratic hurdles for not allowing this useful and simple procedure.

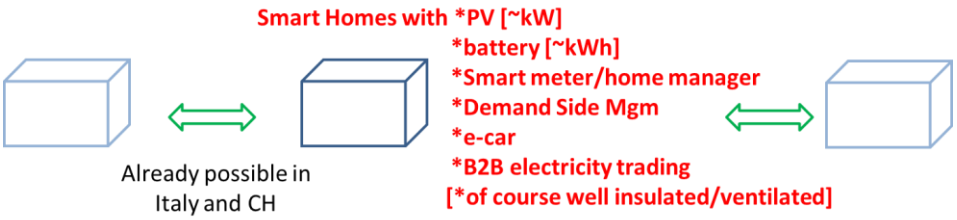

Fig. 2: 1st building block consists of individual and adjacent smart homes (family houses, offices, SME's)

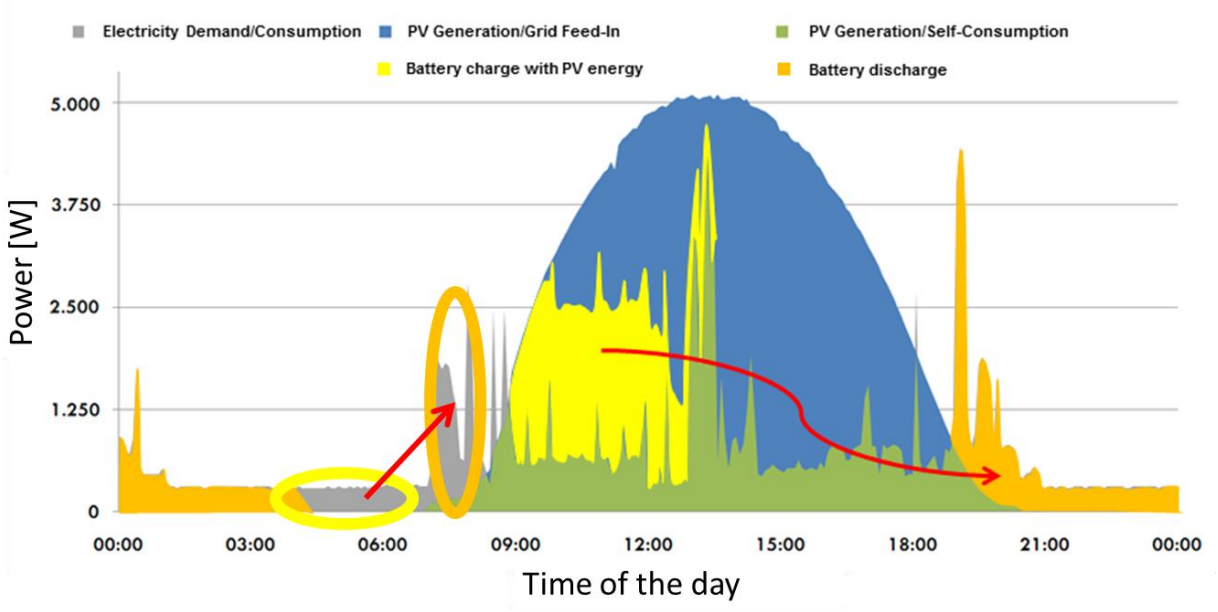

Fig. 3: Load profile for a German home and PV –profile (blue) [1]; shift of PV-electricity from morning/afternoon hours to evening peaks and night electricity to morning peaks by battery storage are indicated (red arrows)

2.2 2nd building block

The second building block is the municipal community. They will run in the near-by region wind mills to leverage the seasonal variations from wind and solar. Also they collect the surplus of not self-consumed electricity to store in larger battery systems (M-/GWh) and redistribute in their area. A small rest of energy which can still not be satisfied cost efficiently by the described steps can be provided by P2G (power to gas), run by surplus of wind and PV electricity. The example of Germany, where 150 energy regions have already firm plans to cover their energy needs by renewables only shows that beside the technological components there is also a political will and support from many citizens that the described path is not an idea only but already taken in reality.

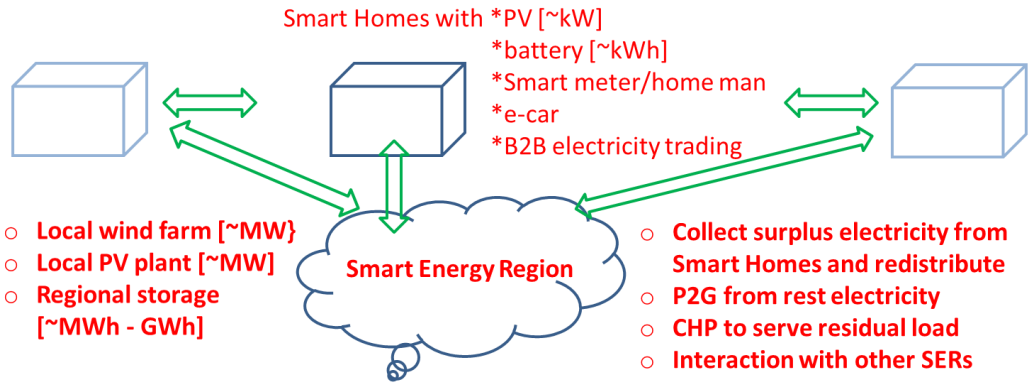

Fig. 4: 2nd building block consists of smart energy regions

2.3 3rd building block

The third building block is the communication with adjacent municipalities first and on a national level the integration of powering the needs for the big industries by renewables only. As shown for Germany there are well documented studies (e.g. from the Fraunhofer ISE) which conclude that a renewable scenario for heat and electricity is (1) possible by 2050, (2) does not cost more than the business as usual case but offers much more internal value added and – last, but not least – (3) helps the planet to survive without CO_2 emissions from transportation, electricity production and heating and cooling needs.

The three building blocks are summarized schematically in Fig. 7.

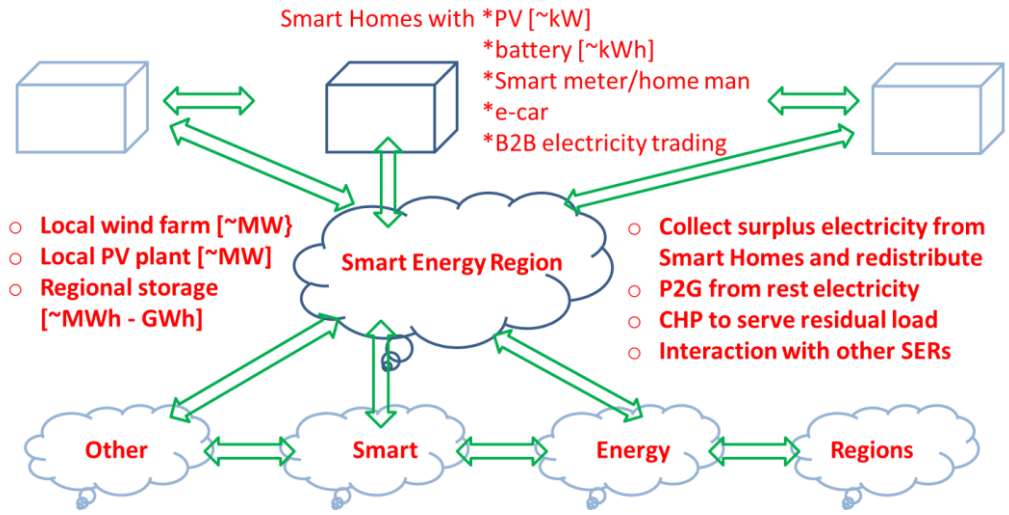

Fig. 5: 3rd building block is characterized by communication between adjacent smart energy regions

The three building blocks are complemented by GW-scale off-shore wind and/or PV farms for energy intensive industries (e.g. steel, Aluminum, silicon).

In order to minimize the needed storage capacity for a region (or country) it is important to have a locally dependant ratio of PV and wind systems installed. The monthly variation for a unit power of PV and wind is shown for Germany in Fig. 6. While in winter months there is high output for wind and low for PV the situation reverses in summer months. If we add the monthly power of wind and PV there is a balanced monthly power output throughout the year. The consequence is that we do not need a seasonal storage but only a balance within a month. With one unit of power (W) we produce one unit of energy (kWh) for PV and two units for wind. Hence the ~600 TWh electricity used today in Germany could be produced with 250 GW PV (=250 TWh) and 200 GW wind (=400 TWh). The surplus of 50 TWh are foreseen to balance the losses for storage and P2G. In the future, when mobility is also fuelled by electricity (or fuel made by electricity) these numbers may increase by 50%, maximally double. The sun belt region worldwide, where most people will live in the coming decades, will favour even more PV relative to wind, due to the much less monthly variation and ~doubling of energy output for PV (~2kWh/W_{PV}).

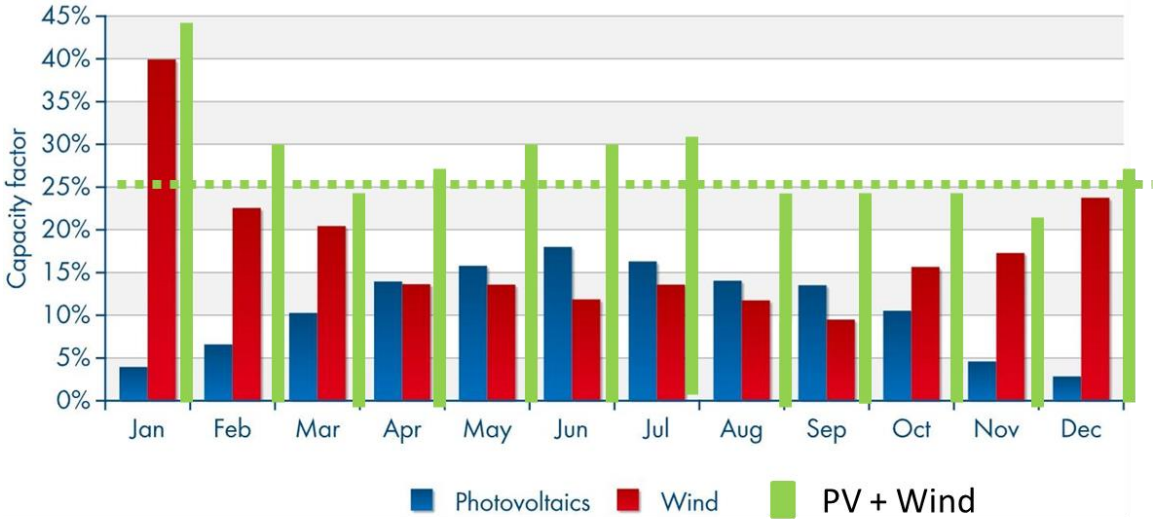

Fig. 6: Average monthly grid feed-in of equal PV- and wind-power in Germany [1]

3 Economical considerations

If the renewable world were only good for the environment and would be more expensive compared to the traditional business as usual it is sad to say that we then would have to wait for quite some time – until the externalities like sea level rise, heavier storms etc. would dictate the change, unfortunately too late by then. Fortunately, the cost development for the two major renewable technologies, wind and PV, has demonstrated in recent years a dramatic decrease. It is often argued that competitiveness of PV on-site generated electricity compared with grid electricity is only reached with support measures like FiT (Feed-in Tariff), especially in countries with minor sunshine like Germany (~1 kWh/W_{PV}). In the following it is shown (see Fig. 7) that in a situation as of today the annual cost for electricity is not only cheaper with a PV system with FiT compared with grid electricity but even more when a battery is included. The benefit for the battery system increases further if an annual increase for the grid electricity is assumed as indicated.

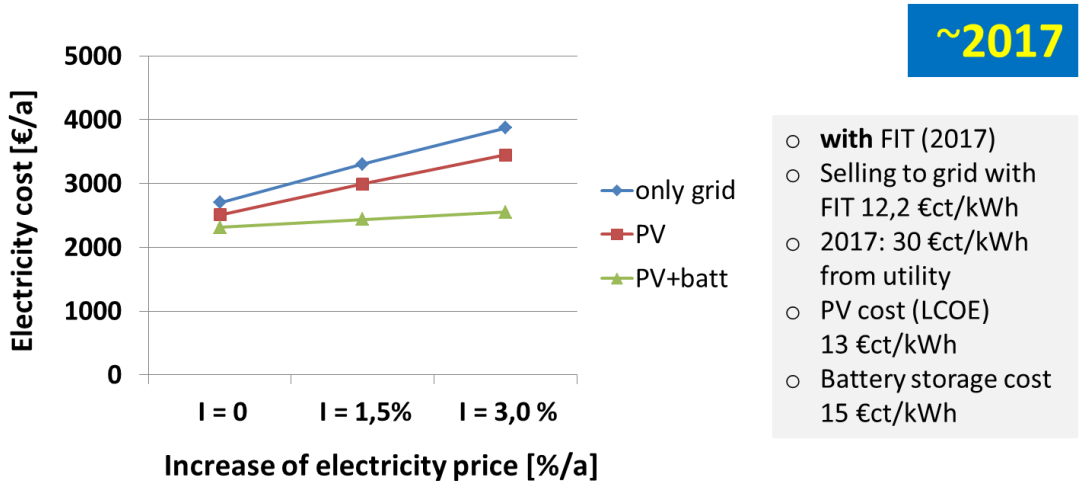

Fig. 7: Annual cost for 9.000 kWh household (a) only utility, (b) +PV (20% self consumption) und (c) +PV+batt (80% self consumption); cases (b) and (c) with FIT

This situation changes significantly if we assume a situation without FiT which in Fig. 8 is taken arbitrarily in the year 2022. Here the PV system alone is more expensive compared to grid electricity due to the assumed small 20% self consumption. The addition of a battery, however, demonstrates the clear advantage compared to grid electricity: the annual cost is bisected if a realistc annual grid price increase is considered.

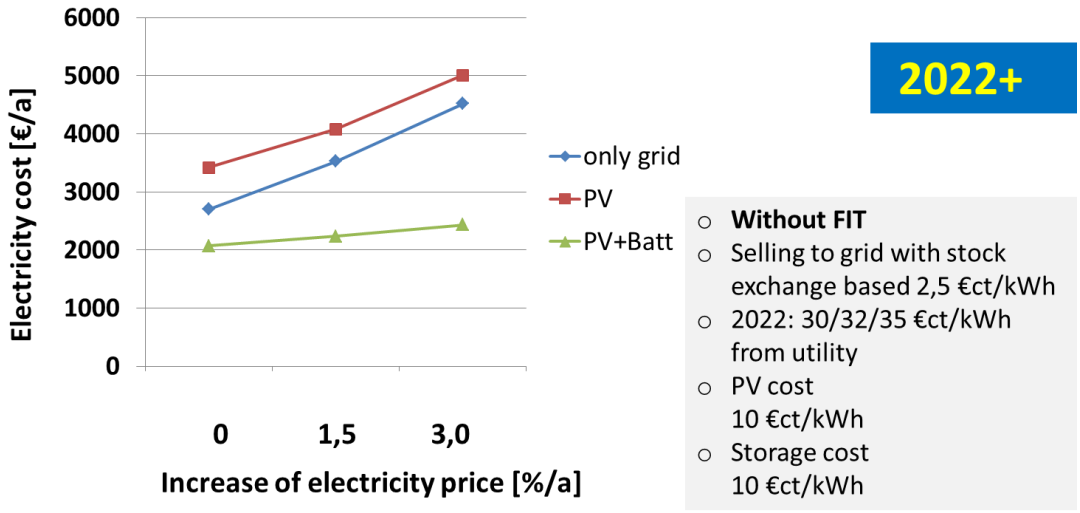

Fig. 8: Annual cost for 9.000 kWh household (a) only utility, (b) +PV (20% self consumption) und (c) +PV+batt (80% self consumption); cases (b) and (c) with FIT

Mass production driven by a phenomenal market growth at a global level has by now proven that even without the inclusion of externalities the Levelized Cost of Electricity (LCOE) for MW-sized PV systems is already today lower than new nuclear and clean fossil. However, even for experts in the field it is quite difficult to calculate a market based LCOE, in order to be able to compare realistically different technologies. In recent years a much easier cost number has evolved, the price for a kWh electricity based on a Power Purchase Agreement (PPA). In this case the investor for a new power plant (PV, wind, nuclear or fossil) sign a contract with the electricity receiving party (utility, SME, industrial company) with well-defined boundary conditions: date of the contract, start of delivery, duration time, price for a kWh electricity, yearly adjustment for inflation to name the most prominent ones. As the negotiation is done with experts from the respective field, the easy to understand kWh-price can be used effectively to compare different technologies. This is done for PV and new nuclear as shown in Fig. 9 based on boundary conditions summarized in Table 1. In the case of PV it has been further assumed that after the typical agreement for new PPA's of 20 years there is at least another 10 years of "Golden Age". This is based on warranty times for quality modules which today is up to 30 years. Hence, if we take very conservatively a maintenance and repair cost, including an additional inverter to meet increasing grid services, of 1 €ct/W in Germany (0,5 €ct/kWh in Middle East) for the 3rd decade of producing electricity, we arrive over the 30 year lifetime of a PV system at an average cost of 3,7 and 1,8 €ct/kWh for countries with German (~1 kWh/W_{PV}) or Near-/Middle East (~2 kWh/W_{PV}) insolation conditions, respectively. If these numbers are compared with the average price for new nuclear electricity, which is between 17 and 29 €ct/kWh for an annual inflation rate of 1 and 2,5%, respectively, the true competitiveness of solar is clearly seen: the addition of storage, which in the future will be below 10 €ct/kWh, brings solar (and wind) away from the old obstacle of being only an intermittent electricity source and is still well below the price for new nuclear (where the price for high voltage grid lines has also to be added).

	Base year	Earliest delivery	Duration [years]	Initial price [€ct/kWh]	Yearly inflation
2 x 1600 MW nuclear (Hinkley Point in GB)	2012	2029	35	12 [2]	yes
~100 MW PV green-field in Germany (~1 kWh/W_{PV})	2018	2019	20	~5 [3]	no
~100 MW PV green-field in Middle East (~2 kWh/W_{PV})	2018	2019	20	~2,5 [4]	Depending on contract

Table 1: Boundary conditions for new nuclear and PV power plants

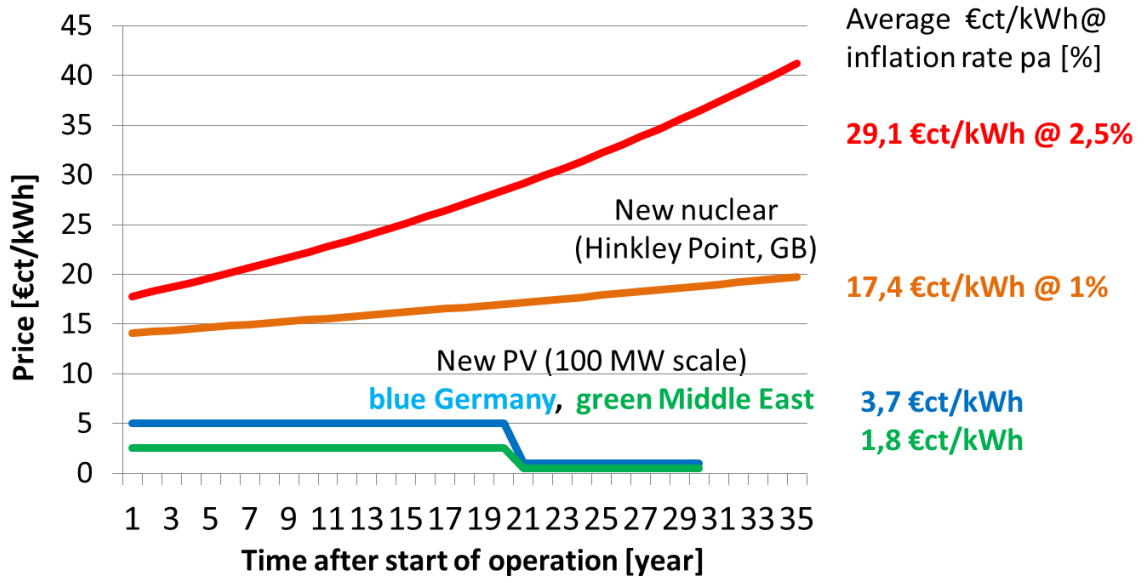

Fig.9: Average LCOE's for PV and new nuclear including inflation

The comparison with new clean fossil plants shows also the superior competitiveness of new solar: if we consider CCS (Carbon Capture and Storage) there is widespread believe that the price for a kWh from such plants is way above 10 €ct. Alternatively, if we assume a carbon price of 50 €/t CO_2, the production cost has to be increased by 6 €ct/kWh for lignite plants, 4,5 €ct/kWh for hard coal and 2 €ct/kWh for gas power stations. Many experts strongly advocate a carbon price of more than 100 €/t in order to combat global warming.

4 Outlook

The countries which follow quickly the renewable path will demonstrate to those, continuing the traditional way using fossil and nuclear for electricity production and oil for transportation, that a

replication makes most sense (1) economically, (2) socially and (3) from an energy security point of view. This will trigger this transformation towards a 100% renewably powered world quicker as many expect also on a global level.

5 References

[1] courtesy of SMA Solar Technology AG (2017)

[2] BBC News (19.03.2013)

[3] https://www.bundesnetzagentur.de average prices for PV PPA's developed from 5,66 to 4,33 €ct/kWh for the bidding process in June 2017 and February 2018, respectively

[4] ENEL Green Power Peru 180 MW project, Dubai Electricity and Water Authority 800 MW project,