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How renewables will change electricity markets in the next five years

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HIGHLIGHTS

- ► Accelerated cost decrease of photovoltaics rapidly changes all cost relations.
- ► PV power starts competing on the retail side, incentive policies lose control.
- ► Cheap solar self-supply pushes energy management and flexibility of prosumers.
- ► Prosumer flexibility challenges grids, requires variable tariffs in time and space.
- ► Bottom-up dynamics require new multi-level governance of grids and markets.

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ABSTRACT

Photovoltaic (PV) cells, onshore wind turbines, internet technologies, and storage technologies have the potential to fundamentally change electricity markets in the years ahead. Photovoltaic cells are the most disruptive energy technology as they allow consumers of all sizes to produce power by themselves—new actors in the power market can begin operating with a new bottom-up control logic. Unsubsidised PV markets may start to take off in 2013, fuelling substantial growth where PV power is getting cheaper than grid or diesel backup electricity for commercial consumers. Managing loads and achieving a good match between power consumption and weather-dependent power production will likely become a key issue. This consumption—production balance may trigger massive innovation and investment in energy management technologies involving different kinds of storage and controls. Increasing autonomy and flexibility of consumers challenges the top-down control logic of traditional power supply and pushes for a more decentralised and multi-layered system. How rapidly and smoothly this transformation occurs depends to a large extent on the adaptation speed of the regulatory framework and on the ability of market players to develop appropriate business models. The paper discusses conflicts of interest; hurdles and drivers; opportunities; and traps for this perspective.

1. Introduction

Two recent developments have changed the context for energy policies: the drastic price reduction of photovoltaics and the Fukushima nuclear accident. Both developments are leading to shifts in public perception about traditional energy sources and differences in costs of production. Their combined impact is to accelerate a global transition to distributed power generation with renewable energies. The present article argues that a point of no return may have been reached: While for decades energy pioneers and dedicated political groups have promoted renewable energy technology in a small number of countries, today technological and industrial dynamics are driving the transformation, at least in the electricity sector. The article explains the reasons why change may occur much more rapidly than expected and why it will profoundly transform the logic of electricity systems and electricity markets—in essence, millions of consumers are starting to produce electricity for their own needs with the help of new kinds of smart consumer technologies.

The transition, however, will not be an easy one. A series of hurdles have yet to be overcome. How rapid and smooth the transformation will occur strongly depends on the evolution of regulatory frameworks. While strong business dynamics pushing for an accelerated transition to renewables is good news for climate policy, powerful incumbents in the power business fear they may lose influence. Their strategies to delay change or to push for centralised renewables may influence developments in single countries. Understanding the transition forward, however, is essential for all businesses and economies, as energy production and consumption patterns are conditioning the fabric of civilisations, economies and products. Adapting to inevitable changes in time may soon become essential for competitiveness in many industries.

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In the last five years, two unprecedentedly rapid changes in perception have transformed the energy policy arena. In 2008/2009, renewable energies suddenly became a top issue of global economic and industry policy focus—President Obama was elected with renewable energy high on his agenda; economic recovery plans in many countries had an emphasis on renewable energy; the European Union decided on binding targets for renewable energy shares in 2020; the International Renewable Energy Agency (IRENA) was founded in record time; the International Energy Agency (IEA) boosted its activity on renewables; and China set off a wind energy boom. Shortly thereafter, in the run-up to the Copenhagen climate conference in December 2009, key stakeholders in Europe started to look seriously at the 2050 horizon and realized that nearly 100% renewable energy production is not only necessary for climate policy, but also technically and economically feasible, at least in the electricity sector. Most scenarios discussed today have been initiated in this phase.[1] They mainly rely on wind energy and assume that strong political support will be needed for quite some time. The recent evidence of the potential of photovoltaics, and the experience of Fukushima have yet to be understood and integrated into scenarios and strategies which will further deepen and accelerate the paradigm change in energy policy.

2. The disruptive character of Photovoltaics

2.1. A radically new technology for power generation

Photovoltaic (PV) cells are semiconductors that directly transform sunlight into electric power. Compared to all other power generation technologies, they have four fundamental characteristics that set them apart:

1. Durably encapsulated and fixed on a support exposed to the sun, they are extremely reliable—they have no moving parts, need no fuel, and require essentially no maintenance during their lifetime of over 20 years.
2. PV cells can be mass produced. They demonstrate similar economies of scale and learning curves as other components produced by the semiconductor industry—for the past 30-plus years, their price has dropped on average by more than 20% for every doubling of the production volume. There is also no end to this trend in sight, as a long list of planned innovations on several separate technology tracks promises further progress for many years.
3. As the transformation of light into electricity occurs at microscopic levels, photovoltaic technologies are extremely scalable. Whether mounted in small watches, on cars, on roofs, or in large power plants, the efficiency does not change. Cost differences between different scales are only due to different mechanical and electrical integration.
4. Innovation cycles for PV are up to ten times shorter than for conventional power plants. PV plants, large and small, can be installed within weeks, with planning times ranging from days to months, depending on the size of the plant.

There is a major difficulty, however—without sunshine, or at least daylight, there is no power generation.

[1] (EURELECTRIC, 2010; German Advisory Council on the Environment SRU, 2011; McKinsey & Co et al., 2010; Teske et al., (2010); WWF, 2009; WWF, ECOFYS, OMA (2011)).

2.2. Markets taking off: From political to industrial dynamics

The global PV market has grown from 280 MW p in 2000 to 16,629 MW p in 2010,[2] corresponding to an average annual growth rate of 50%. In the last decade, Germany has been the country pushing the majority of this growth, making up for nearly half of the global market.

The driver behind this development was the creation of stable markets supported by feed-in-tariffs. In the German scheme, which over 40 countries have replicated with various modifications, private solar power producers sell electricity to the grid operators at a price which is fixed and guaranteed for 20 years. Grid operators then pass on the additional costs of this mandatory purchase to electricity customers. This mechanism has allowed hundreds of thousands[3] of small solar power producers to enter the electricity market since low risks, low transaction costs, and high transparency make investments easily calculable for investors and banks. The difficulty with feed-in-tariffs has been to regularly adapt the guaranteed tariff to decreasing system prices.[4] In addition to providing easy access to small investors, most European support schemes offer higher tariffs for small-scale roof-top installations, rewarding their lower impact on landscapes and lower grid costs. In Germany over 50% of new installations are systems under 100 kW.[5]

In the United States the picture is rather different. The most effective mechanism for promoting solar power is the set of Renewable Portfolio Standards (RPS), which require utilities to generate a growing share of their electricity from renewable sources. Therefore, utilities are the main actors, and since they tend to stick to their logic, they mainly build large power plants.[6]

Until recently, the global PV market depended on the policies of a few pioneering countries. With the visible success of photovoltaics this is changing. In 2012, Italy may become the largest market worldwide, and the share of non-European countries is increasing. Many countries have started new, although prudent, support schemes. This means that despite all present difficulties in PV markets, the global supporting environment is getting more stable. Big new markets are emerging in the US, India,[7] China,[8] Japan, and Turkey. They are not all newcomers, however. Under President Carter, the US had a leading role in PV development,[9] and later it was Japan that took the global lead. Both reduced their efforts after some years because of political changes.

The volume and the accelerated growth of the global PV market in the last years—the average annual growth rate between 2006 and 2010 was 80%—has attracted new players and highlighted the unique characteristics of PV. Growing markets and increasing competition have led to an unprecedented price decline. Between December 2010 and December 2011, PV modules from China/Taiwan

[2] (European Photovoltaic Industry Association (EPIA), 2011).

[3] The number of installations in Germany has reached one million in 2011. Press release Bundesverband Solarwirtschaft e.V. 15.11.2012.

[4] Several countries, such as Spain in 2008, the Czech Republic in 2010 and the UK in 2011, have seen PV markets quickly overheat, provoking drastic tariff reductions which destroy capacities and conficence in the technology. Germany has also repeadtedly had delays in adapting feed-in-tariffs, which led to modifications of the adaptation mechanism.

[5] Evaluation of the official data from Bundesnetzagentur by BSW-solar: share of the newly installed capacity in plants below 100 kW; 2009: 66%, 2010: 58%.

[6] Renewable Portfolio Standards are different in nearly every state and often are combined with rules that foster distributed generation. The emphasis, however, is on utility size PV plants.

[7] Grid connected solar electricity investments in India grew sevenfold from 2010 to 2011 reaching $4,2 bn (Bloomberg New Energy Finance 2.2.2012).

[8] China seems to have decided to bet on PV not only by supplying foreign markets: Local installations grew by 500% in 2011, reaching 2,9 GW (Solarbuzz Market Research 14.1.2012).

[9] The "Solar Photovoltaic Energy Research Development and Demonstration Act" voted by the US Congress in 1978 envisaged PV power competitiveness for 1988 (Schleicher, 1981).

have seen a price decline of 48%.[10] Over the last three years, prices for medium-sized PV systems in Germany have decreased by an average annual rate of 21%.[11] These changes in cost for PV relative to other energies have occurred much more rapidly than most expected, and the trend continues.[12]

The PV industry, which has been characterised by pioneering and growing start-ups, is presently undergoing a shake-up in the transition to mass production. Asian producers, well experienced in low-cost high-volume electronics manufacturing and backed by strong capital resources, have discovered the market and succeeded in dominating it.[13] Globally-established corporations with long experience in electric and electronic equipment and consumer goods are also starting to invest heavily.[14]

Taken together, these developments mean that photovoltaic cells are no longer a hopeful technology at the mercy of political support; instead, they have acquired a technological and industrial dynamic, and become an economic factor which is starting to transform markets.

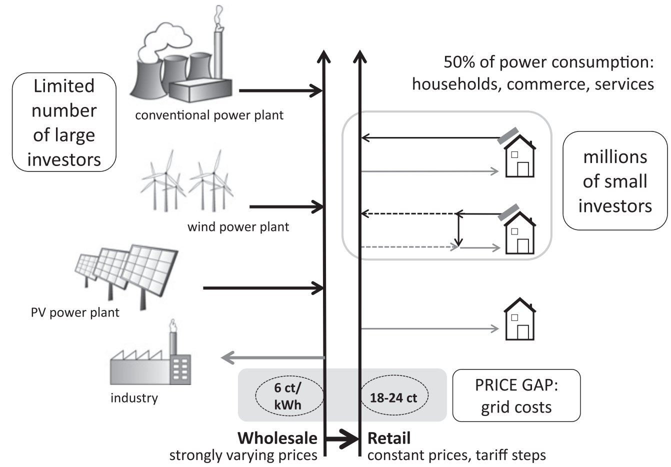

Fig. 1. Modular PV technology: competing on the retail side.

2.3. Competing on the retail side: With grid parity the game changes

In conventional electricity systems, grid costs for retail customers are of the same order of magnitude as generation costs.[15] This phenomenon is reflected in considerable differences between wholesale and retail prices of electricity. In a number of countries, however, real grid costs are not transparent due to hidden subventions. Thanks to their modularity, which leads to relatively small differences in power costs from large and small installations, PV can take advantage of this difference. Whereas large power plants have to compete with the wholesale price, small PV plants on customer's roofs may compete with the retail price, provided the electricity can be directly used on the spot.

Much earlier than expected, "grid parity" for households has been reached in Germany at the beginning of 2012, as the feed-in-tariff for small roof-top installations is lower than the average residential electricity tariff. Due to the mismatch of sunshine hours and residential electricity consumption, however, households have difficulties using more than 35% of their rooftop electricity production for their own needs, unless they make supplementary investments.

This situation is different for commercial units, which in Germany will reach grid parity in summer 2012 when feed-in-tariffs will drop again.[16] Since shops, small industries, services, and office buildings often need most of their electricity during daytime, they will switch to captive power generation when the price difference between roof and grid power becomes compelling enough, and as far as they have sun-exposed surfaces at their disposal (Figs. 1 and 2).

2.4. Two scenarios for Germany

The speed at which the price difference increases is largely underestimated. Until now, decreasing PV costs were compensated by decreasing feed-in-tariffs, so as to keep investors' margins within a reasonable range. But now PV is starting to compete with slowly growing electricity retail prices, and the gap is widening rapidly. Consider a rather moderate scenario in which PV system prices go down by 10% per year, compared to 21% average annual price cuts in the last three years. Further assuming that average electricity retail prices are growing annually by 3% and that feed-in-tariffs fairly represent PV system costs, calculations show that by mid 2016, rooftop electricity delivers 40% cheaper electricity than the grid, also for commercial use (see Fig. 3).

Inevitably this rapidly growing price difference between PV power and grid power will at some point result in considerable investments into captive power generation.[17]

The year that PV-based captive power generation becomes profitable, without supporting feed-in-tariffs, depends on the size of the PV plant in relation to consumption and on the specific load curve of the consumer. This curve may include peaks that do not allow for a simple calculation with averages (SMA, 2011) (Bukvić-Schäfer, 2011). The following cases show that in the moderate scenario, captive power generation without support becomes a compelling option for an important share of consumers before 2014:

1. For a typical trade with activities between 8 h to 18 h and an electricity consumption of 100 MW h/a,[18] it would be profitable for a company in 2014 to substitute 41% of its electricity consumption from local PV while selling the PV surplus (32% of the production) for a wholesale price of 5 Eurocent. If the surplus could not be sold at all, it would be sufficient to downsize the PV plant so as to provide only 31% of the consumption (and dumping 22% of the PV production). Storage opportunities might considerably increase this share.
2. For a typical household it would be profitable in 2016 to cover 25% of its consumption through local PV, selling 64% of the electricity production at a wholesale price of 5 Eurocent.

[10] pvXchange price index December 2011 http://www.pvxchange.com

[11] From 2008Q4 to 2011Q4, according to the quarterly enquiry carried out by EuPD on behalf of BSW-solar: http://www.solarwirtschaft.de/preisindex

[12] A new generation of thin-film module production lines of a major European equipment manufacturer can produce modules at 0.35 €/W, i.e. 45% below the present market price (www.renewable-energy-sources.com, January 16, 2012).

[13] All top ten PV silicon wafer producers in 2011 are originating in China or Taiwan. Eight of the top ten module producers are from China. (Energy Trend 2012). Recently Foxconn, the leading electronics OEM mass producer has announced its entry into the market.

[14] In 2011 Bosch, General Electric, Total have invested strongly, Siemens, Samsung, LG etc. have stepped up their engagements.

[15] Composition of the electricity price e.g. Municipal Utility Dresden 2011: 24% generation, 4% marketing and administration, 26% grid costs, 9% local concessions, 13% FiT and CHP duties, 24% VAT and ecotax (www.drewag.de).

[16] According to the law EEG 2012, taking into account the new PV installations in 2011: by 15%. An amendment to this law with much more drastic cuts is presently under discussion.

[17] Under the present German law, until 2014 captive power generation is additionally incentivised, further increasing the cost differences calculated above.

[18] Corresponding to the standard load curve G1 as described in SMA (2011). Calculations for this case are based on the corresponding self-consumption curve given there.

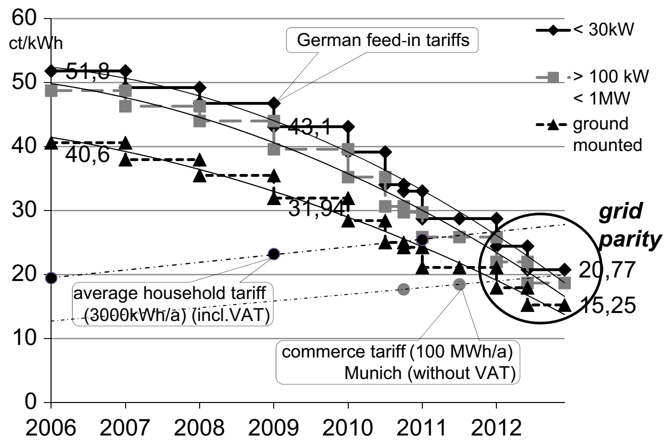

Fig. 2. Evolution of feed-in-tariffs for PV and electricity prices in Germany.

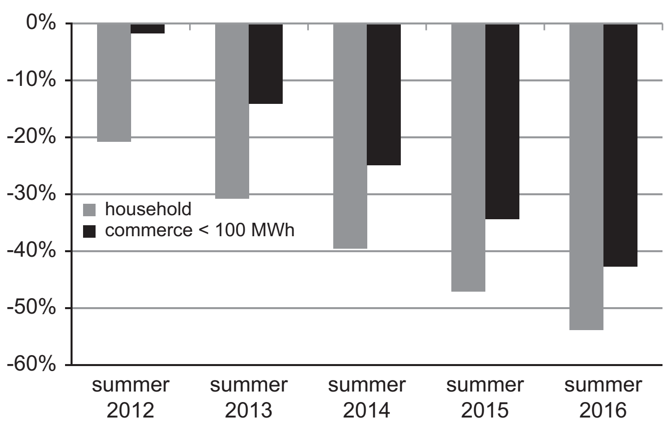

Fig. 3. Growing price difference between PV power and grid power in Germany (moderate scenario: PV price decrease 10% p.a., electricity tariff increase 3% p.a.).

No selling to the grid would require downsizing the PV plant so as to cover only 20% of the needs (wasting 50% of the PV production).[19]

3. Instead of dumping surplus PV during sunshine hours, storage for evening consumption becomes a compelling option with adequate storage prices. However, batteries cannot store between summer and winter. Empirical measurements have shown (Bukvić-Schäfer, 2011) that even at present battery costs a household can profitably cover 42% of its consumption in 2015.[20] Since the shaving of sudden load peaks is important, common batteries for several households would be much cheaper.

There are good reasons to think that the assumptions of the moderate scenario may be too conservative. Looking at the market and the political discussion in Germany at the beginning of 2012, a stronger PV price decline until 2013 seems probable. After the record installations at the end of 2010,[21] there is strong political pressure for an additional extraordinary feed-in-tariff cut, which in turn may accelerate the price race to the bottom amid the backdrop of overcapacities and a fierce competition for surviving the industry shakeup.[22] A plausible "accelerated scenario" could therefore be based on the assumption that the price decline between 2012 and 2013 goes on at a rate of 24% before going down to 10% per year. This would mean that the three cases calculated above for the moderate scenario would be profitable one year earlier. Captive power generation in industry gets more compelling in 2013, while households can cover more than 40% of their needs with PV in 2014 without selling surplus energy. That means that incentive policies might soon loose their capacity of controlling the evolution.

In Germany, a rather northern and highly industrialised country, putting standard PV modules on existing qualified roofs would be sufficient for covering around one third of the overall final electricity consumption.[23] Estimates that include supplementary surfaces (facades, parking lots, brownfields, etc.) or advanced technologies (less sensible to partial shadowing, with higher yields, variable geometries and sizes) result in much higher percentages. On this basis it seems reasonable to assume that the overall potential for self-supply with PV is above 20% of German electricity consumption. Since only half of the electricity is flowing through distribution grids, while the other half is directly going to large consumers, this would mean that in the long run distribution grids could loose nearly half of their throughput,[24] not even considering self-supply with combined heat and power (CHP). The main question is how quickly this potential will actually be realised.

2.5. Grid parity and diesel parity advancing globally

Until now, the focus of this article has been on the situation in Germany. Analysing globally which markets will reach grid parity

[19] According to the graph on page 10 of Bukvić-Schäfer (2011) a plant with 40% capacity of the household consumption would allow for 50% of self-consumption, a plant with 70% capacity only for 35%.

[20] Result obtained by reframing the results of Bukvić-Schäfer (2011, p.21). Taking a market price of 145 EUR for a 2V/200Ah lead-acid-cell.

[21] More than 3 GW only in December 2011.

[22] The experience of the last years has shown imminent strong feed-in-tariff cuts fuel the market to an extent which in turn leads to stronger further cuts. As long as enough PV companies stay in the game and reduce their prices according to lower feed-in-tariffs, the downward spiral accelerates.

[23] (Lödl et al., 2010) estimate the German roof PV potential at 160 GW p, while reserving one third of the surface for solar thermal collectors. Applying radiation data of Frankfurt (878 kW h/kW p), this corresponds to 140 TW h or 27% of the final electricity consumption in 2010 (AGEB 2011). The detailed roof analysis of Berlin (Berlin Business Location Centre 2011) resulted in a potential of 3 TW h/a corresponding to roughly one quarter of the electricity consumption in the city.

[24] This presupposes that electricity consumption remains stable. See below for reasons why cheap PV may cause more electricity use in the heat and transport sector.

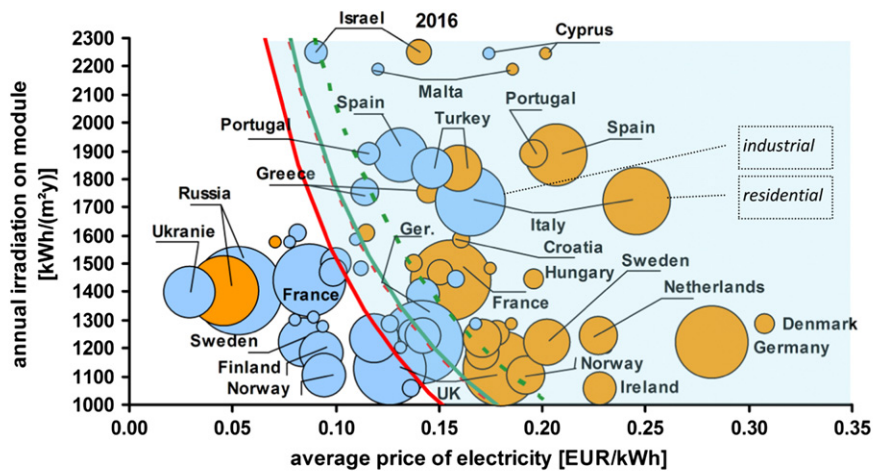

Fig. 4. PV Grid parity in European markets 2016 (shaded area). A 2010 forecast (Breyer and Gerlach, 2010).

soon (Breyer et al., 2011a), two main factors are decisive: the intensity of solar radiation, and the costs of electricity with which photovoltaic power has to compete. In many countries the sun is shining more strongly than in Germany, but in most cases, tariffs of electricity from the grid are lower. Fig. 4 shows a forecast from 2010 for the grid parity situation in Europe in 2016.

In many countries with weak grids, however, grid parity is not the essential turning point for PV to become attractive. Long before, PV power may become cheaper than backup power from diesel generators, which provide an important share of overall electricity consumption (Breyer et al., 2011b). Considering the example of India, around 30% of industrial power consumption is provided by captive power generation.[25] In 2008, 70% of wind power installations were purchased by industry for covering their own power needs (Jones, 2010). Strong growth and weak grids cause public power supply to be cut for several hours a day in many regions. Although diesel fuel is subsidised, electricity from diesel backup systems costs about 15 Rs/kW h, well above present PV power costs which cannot yet compete with grid electricity (around 8 Rs/kW h). A huge potential market is waiting for project developers to gain experience, craftsmen to be trained, appropriate business models to cope with high upfront costs, and finally investors and banks capable of evaluating the remaining risks.[26] Many countries begin to realise that building up the capacity to use these potentials takes time and have started to establish market development programmes as well as to reduce grid power subsidies.

2.6. Load management: A new innovation wave

There are good reasons to assume that considerable new opportunities and potentials for load management will be discovered when commercial consumers producing their own solar power have an immediate interest to cut electricity costs by shifting consumption into the sunshine hours. Until now, utility tariffs gave few incentives in this direction. Basically, there are three options for a temporal management of power consumption:

- Shifting the operation time of power-consuming equipment and processes.

Table 1
Final use of electricity in Germany 2009 (data: Arbeitsgemeinschaft für Energiebilanzen AGEB et al., 2011).

	Heat (%)	Cold (%)	Mech. energy (%)	ICT (%)	Light (%)	Sum (%)
Industry	7.9	1.9	30.6	1.8	2.1	44.4
Trade & services	3.5	2.1	5.7	3.9	10.6	25.9
Housholds	13.7	5.3	0.6	4.6	2.3	26.6
Transport	0.2	0.0	2.7	0.2	0.2	3.1
TOTAL	25.3	9.4	39.6	10.5	15.2	100.0

- Storing energy for shorter or longer periods, in the form of electricity or other forms of energy into which electricity is being transformed during its use (heat, chemical or mechanical energy).
- Integrating additional non time-critical loads (e.g., heating with heat-pumps, charging electrical cars).

Shifting operation times is difficult or impossible when it concerns lightning, communication, or computing. It is also mostly impractical when it concerns running machinery, except in cases like factories, with hundreds of thousands of workers in India working at night because electricity is cheaper and has less power cuts. In many cases, however, operation time shifts are intertwined with some kind of energy storage.

Storing electricity is in many cases the most costly option. Most electricity is transformed into other energy forms before final use. In Germany – where air conditioning is much less important than in other countries, such as the US – heating and cooling make up 35% of electricity consumption, while mechanical energy makes up 40% (see Table 1). Storing heat and cold is much cheaper than storing electricity. Mechanical energy in industry and trade is to a large extent (estimates speak about up to 50%) provided through compressed air systems which can be equipped with larger pressure vessels. Households, using only one quarter of overall electricity consumption in many small devices, have less potential for load management than other sectors. Trying to tap the potential, however, would require analysis of processes and options in detail.

As heat storage is cheap, making the best use of fluctuating solar power supply may also include substituting other heat sources by electric heat pumps. A more intense coupling of electricity and heat systems at all levels via heat pumps, cogeneration and possibly hydrogen and synthetic methane will

[25] PriceWaterhouseCoopers, 2003. Infrastructure Development Action Plan for Chhattisgarh – Final Report, Annexure III.2: Captive power scenario in India. cg.gov.in/opportunities/Annexure%25203.2.pdf.

[26] Personal communication from industry, regulator, and utility representatives, Bangalore, Mumbai, November 2011.

surely play an important role. Another interesting option for a flexible additional use of solar electricity is charging electric vehicles during daytime.

With all these approaches, consumers' ability to self-supply electricity, in order to optimise the match between production and consumption, would need sophisticated electronic energy management systems. These systems would continually check and optimise a large number of parameters in their homes, factories, offices and buildings. The industry for such smart devices and systems is currently fragmented, and cheap distributed computing power, improved communication and cloud computing, new solid state power electronics, and new software concepts open a wide range of new opportunities. However, large multinationals have started to invest heavily into vaguely-labelled smart home, smart grid, or smart building technologies, promoting rather different concepts. Estimations for smart grid markets in the next years reach up to $ 100 bn, strongly depending, however, on the definitions adopted.[27]

For these reasons, if the ongoing price slide of photovoltaics leads to a boom of captive power generation, it is probable that a wave of innovations in energy management technologies will follow suit. While continuous progress in PV power generation can largely be taken for granted, energy management, storage, and new system configurations may come up with some surprising innovation. PV not only empowers the consumer to produce cheap electricity on his own, it also encourages him to reconsider his energy production, consumption, and trade in light of new technologies and in a systemic perspective. System competence becomes essential for those wanting to make business in the field of captive power generation.

2.7. The energy prosumer: An emerging role

The scenario of a surge in captive power generation with PV relies on the assumption that power consumers are willing and able to also become producers, or "prosumers."[28] In most cases, the self-supplying electricity consumer will maintain a strong exchange with the grid, governed by public regulation. Technically, the potential is large. Economically, conditions are getting ever more attractive, however, there are some obstacles that may cause delays.

Developing a new role requires learning on all sides and takes time. The start is rather simple. Further optimisation involving load management and storage can occur in several steps. For becoming a mass phenomenon, the role of prosumer will have to be low risk, involve well-defined options, and rely on well-known models. Solution providers will have to play an important role in structuring the multitude of situations and opportunities, making it easier to convince customers and to rapidly implement standardised solutions.

2.8. Factors that might slow down this bottom-up development

Developing successful business models in this context will require bringing together knowledge and experience of what have been separate industries. Developing and rolling out more or less standardised packages to well-defined groups of customers and branches will require a combination of capacities in photovoltaics, communication and control, building equipment, and manufacturing engineering in different branches, combined with financial engineering and possibly also investment capital. A number of international mergers and acquisitions can be interpreted as major players starting to perceive this as a strategic issue.[29]

Another important challenge is to deal with high upfront costs and long lifetimes of an investment that most companies do not consider to be their core business. Contracting and leasing are promising approaches to solve this problem and are easy to apply as long as subsystems and responsibilities can be clearly defined. It gets more difficult when energy management is intertwined with production processes, as the slowness of investments into rewarding energy efficiency measures shows. Developing modular offers and step-by-step approaches may be the key for solution providers caring for long-term relations with medium-size companies.

Moreover, the success of photovoltaics itself could be a source of hesitation, as strongly falling prices may lead to postponement of already highly rewarding investments.[30] In markets with a reliable grid connection this effect could possibly delay the take-off of PV-based captive power generation by a couple of years. The advantage of waiting disappears, however, with growing price gaps, and there are other motives to act without delay, including low investment risk, energy security, the risk of decreasing reliability and increasing costs of grid power, environmental concerns, and marketing advantages. Risk perception is therefore important. Here again, contracting and splitting roles could be helpful—while the commercial owner of a roof might be interested in short-term cost-cuts of his electricity bill, the contractor aims at making as soon as possible a low-risk long-term investment.

Another issue might be the development of grid electricity prices. There is widespread consensus that energy prices in general will increase.[31] Moreover, there is growing pressure to cut back fossil fuel subsidies.[32] Conventional electricity, in this context, is expected to get more expensive too. As will be seen in the next chapter, however, depending on the market design, renewables may have a double effect. They may reduce the wholesale price while increasing the average retail price of grid power, which may further increase the competitiveness of captive power generation.

This discussion of challenges shows that there are good chances for the interested industry to overcome the obstacles soon if it undertakes the necessary efforts, and the considerable market potential is a powerful incentive. The resulting major change in market dynamics would mean that most published market forecasts, including those of the photovoltaic industry (European Photovoltaic Industry Association (EPIA), 2011), are too conservative, as they are based on the assumption of a continuous development. Already in the past decade, real development of wind and photovoltaics has outpaced most projections. As long as renewables were a minor phenomenon on electricity markets this did not matter. Meanwhile, however, an underestimation could have serious consequences for the evolution of the overall system.

[27] E.g., China has decided to invest 45 bn $ the next five years into smart girds for integrating renewable energy sources (Hart, 2011).

[28] The term prosumer, i.e., producer + consumer is now commonly used in the context of distributed power generation. It was first coined by (Toffler, 1980). Another meaning is often used in "prosumer products" derived from professional consumer.

[29] Bosch, a strong player in heating and automation systems as well as General Electric, has determinedly entered the PV market. Toshiba has acquired Landis&Gyr, world leader in metering, and Google is investing in renewable energy and smart grid technologies.

[30] If new PV power would cost 40% less than grid power, and one could expect PV prices falling by 10% a year, one could additionally save in the range of 4 per cent over 20 years postponing the investment by one year (assuming grid power prices rising by 3% p.a., no repowering, a discount rate of 4%); with a price decrease of 5% postponement makes no sense. A detailed calculation would have to take into account additional parameters such as investment alternatives, financing structure, time horizon of the calculation, assumptions about repowering etc.

[31] Cf. the IEA World Energy Outlook 2011. The reasons are increasing global demand, depleting fossil fuel reserves, decreasing contribution of nuclear power and increasing environmental and security requirements. The emergence of cheap shale gas is expected to have an impact which will not invert the overall trend.

[32] According to IEA (2011), in 2010 fossil fuel subsidies amounted to 406 bn USD while subsidies for renewable energy sources reached only 66 bn USD.

The developments summarised in this chapter indicate that it is reasonable to consider the possibility that in the range of three years – and it is possible that it will take less time – there will be a series of countries with a consistent and growing number of business units and private homes producing their own electricity while still interacting with the grid. Increasingly they would be able to manage their energy system so as to optimise at any moment the combination between producing power and consuming power, as well as purchasing from and selling to the grid. The questions that remain are what this would mean for the grids, how it would affect electricity prices, and how grid operators and regulators would need to react to such a development?

3. Towards a new control logic of the electricity system

3.1. Dealing with fluctuation

In the course of industrial development power plants have grown and so have the public utilities, which in many countries have become national monopolies. The increasing need for stable power supply through public grids has required increasingly sophisticated methods of balancing electricity production and consumption at every moment since electricity storage is expensive. Basically, the approach has remained the same for more than a century—production has been centrally regulated so as to follow demand. The behaviour of large numbers of customers was sufficiently predictable for a rough planning of production timetables, and fine tuning was essentially done on the basis of norm deviations of frequency and voltage. Power plants could produce anytime on demand, and different types of plants were developed for different roles. Large plants with low costs and slow dynamics (coal, nuclear, river power) operate for the base load around the clock, while more quickly reacting and often more expensive plants (gas, oil plants, hydropower reservoirs) operate for middle and peak power. Technological progress essentially focussed on more efficient use of fuel and less toxic exhaust gases. This progress led to power stations growing in size, in some countries complemented by smaller combined heat and power plants.

This well established system is being deeply challenged by the switch to renewable energy sources (German Advisory Council on the Environment SRU, 2011). Power generation with wind and sun depends on natural conditions; moreover, marginal costs of these resources are zero, since the costs are the same whether the plant is running or not. As the share of wind and sun power increases, the base load concept runs into troubles: More and more often the whole consumption is covered by fluctuating renewables which need rapid compensation when their production fluctuates. Dealing with this fluctuation has become the central issue of the transition towards renewables.

Confronted with this challenge, the centralistic production-focused paradigm of the incumbent large utilities suggests bold answers, including large wind farms off-shore where the wind blows more continuously; large cross-continental transmission lines for compensating local variations; and large systems for storing electricity. This approach requires large amounts of capital, large infrastructures, long planning and permitting times with many actors involved. It corresponds to the historical experience of the incumbent organisations. Development of new semiconductor technologies may, however, provide answers that are more flexible, less expensive, and which grow more rapidly.

PV-based captive power generation is strongly motivating to deal with fluctuation locally. In-house power management – using advanced information and communication technologies – will create a new temporal flexibility of electricity consumption by smartly exploiting control and storage options in the final use of electricity. This new end-user flexibility may be used for strengthening the stability of the grid and its capability to deal with fluctuation, or it may destabilise the public power system if incentives are not set adequately.

3.2. Captive power production challenges old grid logic

Partially self-supplying electricity consumers connected to the grid will optimise their purchase and selling of power according to their own logic. This may not necessarily correspond to grid stability requirements. Without supplementary incentives, the grid would be essentially used as a compensating buffer, with consumption peaks in the evening when the sun does not shine, or sudden feed-in peaks at noon when the own consumption capacity is exhausted, or on weekends. This fluctuation would result in less electricity transported through the grid combined with a stronger dynamic. A high share of such customers in a distribution grid may have destabilising effects and will drive up grid costs per kilowatt-hour delivered. Already today, local grids in rural areas with high concentrations of distributed energy resources have to make additional efforts.[33]

From the point of view of the public grid, increasing captive power generation will therefore require a set of conditions and incentives that allow the new flexibility on the consumer side to help manage fluctuating power production in the overall system, instead of creating additional problems. Considering economic incentives, the short-term interaction of the prosumers with the local grid can essentially be influenced with time-dependent tariffs for electrical power (kW) and for electrical energy (kW h), for selling power to, and for purchasing power from the grid. In determining such tariffs to apply there is a series of challenges.

The biggest difficulty is that the strongest effects of captive power generation will be felt in local grids. Proper incentives must be set at the local level since the requirements will strongly differ between places, depending on local wind and sun power generation, on the behaviour of large local consumers, and on the available grid connections. In the present regulatory framework, it is unclear how and by whom such locally adapted tariffs should be defined, adapted, and applied.

It is generally acknowledged that as renewables increasingly become the dominant mainstream power source, the present feed-in-tariffs will not be appropriate anymore. However, fluctuating renewables cannot be simply integrated in the present electricity market, which was constructed for centralised fuel-based power generation. Distributed power generation, and more so increasing captive power generation involving a surge in the number of power producers and self-optimising systems, require a completely different market architecture. New tariffs should ensure equitable conditions for all. In particular, for small investors they should provide easily understandable reliable frame conditions for long-term investments, which was one of the success factors of feed-in-tariffs.

3.3. More complex optimisation in space and time

The ongoing liberalisation of electricity markets in Europe essentially relies on the assumption that the spatial dimension

[33] See Roland Berger Strategy Consultants, Prognos AG (2010), p. 82 ff. E.g., the regional DSO E.ON edis in Brandenburg and Mecklenburg-Vorpommern (eastern Germany) already has a renewable power share of 50% and invests strongly in appropriate substations and connections. The corresponding costs are not redistributed at the national level as the feed-in-support, but must be born by the local clients. (Press release E.ON edis 2011-05-23). However in Germany additional efforts for PV will remain limited (BSW-Solar, 2012). In weak or strongly growing grids a smart integration of captive power generation may lead to considerable savings.

Table 2
Increasing complexity of the approaches for matching consumption and production of electricity (the size of the circles represents the importance).

Approaches for matching consumption and production of electricity			
	Conventional central power plants	**Centralised fluctuating renewables**	**High share of distributed fluctuating renewables**
Production management	**Central** management	Also for wind & sun	Mainly with CHP
Spatial compensation over grids	**Central** control: predictable average loads	New and continental transmission grids	**Bottom up** demand: more international exchange
Consumption management (demand side)	Widely abandoned, nearly no incentives	Not encouraged	**At all levels** high innovation potential
Storage	**Central** pump storage for buffering base load nuclear	Central storage	**At all levels** high innovation potential

does not matter.[34] Historically, in industrialised countries the grid structure has grown hand in hand with the development of the system of large conventional power plants, owned and planned by the same monopolistic public utilities. Distribution grids were conceived to distribute centrally generated electricity. As a result, not only the technical characteristics and the control logic of the grid system correspond to the needs of this kind of power generation, but also its spatial patterns. In European markets, grid costs, including ancillary services, are essentially attributed by administrative procedures.[35] Electricity is increasingly traded on power exchanges at the national level.

The emergence of distributed wind power and photovoltaics not only fundamentally changes the time parameters of power generation (fluctuation), but also spatial patterns and the importance of differences between local conditions. PV and onshore wind plants of all sizes are much smaller than conventional power plants; they feed into low or medium voltage lines. Photovoltaic power in particular can to a large extent be generated in the immediate vicinity of consumption points, reducing the necessity of transmission. Old power plant siting criteria, such as rivers (for cooling) and ports or coal mines (for the supply with fuels) have lost importance, while new ones are areas with high solar radiation, wind speed, and available space. Old grid patterns are therefore increasingly inadequate, not only concerning the layout and capacity of transmission lines but also in the relationship between distribution and transmission networks. Different approaches to renewable power generation deployment will require different grid topologies.

Until now, the discussion on the implications of different scenarios has not yet really started.[36] Claims for doubling the transmission capacity until 2030 are not founded by transparent calculations of alternatives. The scenarios of transmission system operators (ENTSO-E, 2010) show that maintaining the fiction of a copperplate is getting increasingly expensive. Geography matters.

Moreover, the interrelation between time and space gets more complex. In the conventional system, generation management and also interregional compensation were used for matching production and consumption; international exchange was used only to a very limited extent. With an increasing share of fluctuating generation, which offers very limited possibilities of management, other options have to be used more intensively (see Table 2), including long-distance exchange (spatial dimension), demand side management (time dimension), and storage (time dimension). Their relative cost (or availability), and therefore optimal mix, inevitably varies from place to place and will change over time (e.g., with cheaper storage technologies). Also, concepts focusing on centralised renewable supply (e.g., offshore wind) and investing heavily in transmission lines cannot completely escape the need for a more complex optimisation.

A strong growth of captive power generation and prosumer flexibility exacerbates this trend. Prosumers themselves start to optimise with production management, consumption management and storage, obliging higher tiers of the overall system to react.

[34] An exception are some interesting approaches in the UK (Brandstätt et al., 2011).

[35] At least in Germany, grid costs are attributed in a way which is independent from time and space—it only depends on the tension level of the connection and has a power (kW) and an energy (kW h) component (StromNEV 2005).

[36] Scenarios such as those from the European Climate Foundation (Hewicker et al., 2011; McKinsey & Co et al., 2010), the grid study from Greenpeace (Greenpeace, EREC Europen Renewable Energy Council, 2010) the Germany scenarios from SRU (German Advisory Council on the Environment SRU, 2011) or the recent Roadmap 2050 from the European Commission (European Commission, 2011a) call for massive investments in grids (EU commission 1.5 to 2.2 trillion EUR between 2011 and 2050) but do not really compare the grid implications of different supply approaches.

3.4. Active distribution networks

Today, at least in Europe, distribution system operators (DSOs) have only very limited balancing activity. Backup and ancillary services are being organised by the transmission grid operators. Most consumers, in Germany all below 100 MW h/year, are being taken into account by simply using their standard load profiles. When they start producing power themselves and developing own consumption flexibility for dealing with fluctuating generation, this standard profile approach does not work anymore. Local grid operators need to look more carefully at their own balance for avoiding dangerous or inefficient new load peaks in all directions. They need to set specific, time-dependent incentives for balancing the producers and consumers in their grid to a certain extent, before relying on balancing services from the level above. This would completely reverse the logic of the present system. Pushed by the new balancing capacities of the prosumers at the bottom of the pyramid, balancing starts to be organised bottom-up. But under the present rules in Europe, distribution system operators have no possibilities to fulfil such a role. Unbundling has separated the roles of energy provider and grid operator.

Internationally, the increase of distributed energy resources (DER) and the availability of new semiconductor-based power electronics have led to an increasing interest in "microgrids" and active distribution networks, not only for remote areas, but also as a utility strategy. A useful overview on these concepts is given by Chowdhury et al. (2009), however their use by different authors and projects is not yet coherent.

In the US, where grids are less dense and power quality is lower than in Europe,[37] this debate has gained in intensity over the last decade (Driesen and Katiraei, 2008; Lasseter, 2002; Marnay, 2011). Recently, the IEEE has adopted a new standard (IEEE Standards Organisation, 2011) that gives guidance for the integration of microgrids into electric power systems. In combination with initiatives of the Federal Energy Regulatory Commission for enhancing demand response (FERC and DOE, 2011) it might strongly facilitate the implementation of grid-tied microgrids (Carson, 2012).

Europe seems to have come a bit later in this development but meanwhile there is intensive research on active distribution networks. In the ambitious project EcoGrid.dk the Danish grid operator ENERGINET[38] sketches the architecture for a grid that can accommodate 50% wind energy (Lind, 2009) emphasising the importance of active distribution and of decentralising operation and control. But while the technical reports are explicit on this subject, the summary report is more cautious about decentralising competencies.[39] The strategy of unbundling pursued in the last decade in Europe is not fully compatible with the idea of integrated management underlying the microgrid concept,[40] which is perhaps the reason why the term "microgrid" has become rather unusual in Europe.[41] Among the EU projects in this field, the DISPOWER project (Degner et al., 2006) was one of the first to systematically address new functioning modes of distribution systems for coping with high shares of distributed energy resources. Today, the ADDRESS project[42] (Valtorta et al., 2011), with the participation of large European utilities is looking at a more flexible and responsible role of DSOs. For reconciling a stronger role of prosumers in balancing the system with present market structures it envisages to introduce "aggregators" mediating between prosumers, DSOs and national markets for ancillary services. Aggregation – also in the form of virtual power plants – is a concept frequently referred to in a variety of projects[43] which originally does not take into account physical grid capacities. It seems to be an open question how this concept can be transparently combined with an enhanced role of DSOs, so as to really allow for optimal local balancing. Rather advanced in the search of new optimisation mechanisms at the local level are six model regions financed under the programme "E-energy—smart grids made in Germany," [44] which develop technical platforms for local electricity markets. Interestingly, municipal and independent regional utilities play an important role in these projects. But also these do not directly address the question whether it might be useful to reconsider the whole market architecture. They are all technology-oriented and try prudently to integrate innovative technological concepts into existing market and institutional structures. The same can be said of most of the wider range of projects dealing with "smart grids" (Giordano et al., 2011), a broad term embracing a wide variety of concepts.[45]

After the blackouts and the crash of ENRON in 2002, several states in the US have successfully introduced the market concept of "nodal pricing" for an optimal allocation of grid capacities in transmission grids. The concept[46] allows for a direct consideration of grid topologies and location specific pricing. Also, in Europe it is supposed to have considerable advantages for changing requirements in transmission (Vogel, 2009; Weigt, 2006). In the EU, Poland is presently testing the concept for its transmission grid (Sikorski, 2011). More recently, it has been suggested for managing distribution grids (Sotkiewicz and Vignolo, 2006)—an idea which does not yet seem to have been further developed systematically (Brandstätt et al., 2011; Neuhoff and Boyd, 2011).

Locational pricing in one form or another will be an essential element of a new market architecture that would be able to optimally balance production and consumption of electricity in time and space with the help of transmission and storage.

3.5. Towards subsidiarity: Bottom-up growth of a more balanced multi-level system

Evidently, the question of the overall architecture is a political one.[47] There is little systematic discussion concerning basic

[37] Avoiding breakdowns of the whole system by enabling a temporary islanding of small parts of the grid has been an important issue.

[38] Denmark has been rather early in discussing these issues because of its high share of wind and CHP in electricity generation and its partly insular structure.

[39] "However, it is understandable that the idea of splitting the system in subsystems not only technically but also organisationally will meet resistance." (Trong et al., 2009 p. 22).

[40] See (Energietechnische Gesellschaft im VDE (ETG), 2008, p 77 and Fenn et al., 2010).

[41] After the EU projects MICROGRIDS and MORE MICROGRIDS http://www.microgrids.eu which ended in 2009, the term has not been prominently used in major projects.

[42] ADDRESS http://www.addressfp7.org

[43] Most explicitly in the FENIX project http://fenix.iwes.fraunhofer.de/

[44] Programme e-energy: http://www.e-energy.de/en/. Most interesting: the project E-DeMa http://www.e-dema.de/de/index.html, and the project MoMa http://www.modellstadt-mannheim.de.

[45] However, distributed intelligence across all scales of the grid is a common feature. A series of technologies can be used for implementing a variety of different functioning logics. The head of a larger independent German DSO uses the term more specifically. In his view, a smart grid should have the size of a municipal utility, i.e., in Germany there would be a need for 100 to 200 of them, and would be composed of more automated microgrids which cater for a more specific local balance (Fenn et al., 2010).

[46] Originally developed by Sweppe et al., (1988) and further developed for congestion management by Hogan (1992).

[47] The smart grid report of the renowned VDE (German Association for Electrical, Electronic and Information Technologies) puts it the following way: "The unbundling encumbers the implementation of optimal concepts since the defined market roles (generation, grid, consumption etc.) do not correspond to the physically necessary system approach and are characterised by corresponding limitations and partial interests. Nevertheless the political requirements have to be implemented since putting them into question is not conducive at present." (Energietechnische Gesellschaft im VDE (ETG), 2008, p 77.

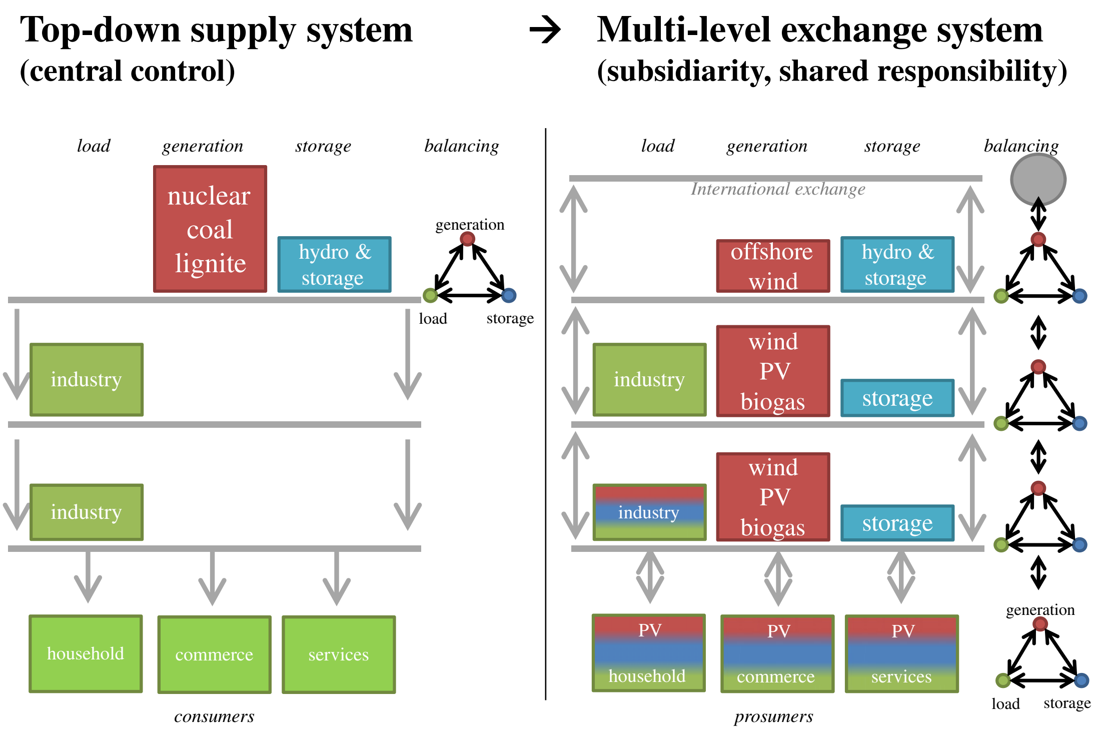

Fig. 5. Transformation of the electricity system—schematic representation.

control and governance approaches as well as system typologies. The transition from the old central control approach, where customers could be treated as statistically predictable units, towards a system with much more self-organisation growing from the bottom is a complex process involving not only technical innovation but also strong economic, institutional, and political interests. The definition of coordination levels and the design of markets strongly affect power relations between the actors. The generally acknowledged need for more distributed generation, distributed grid intelligence and active balancing in distribution networks is weakening the position of large utilities.

This can be clearly seen in Germany, where the four large incumbent companies lost market shares and increasingly also political influence, while municipal utilities are getting stronger.[48] In 2010, 51% of the installed renewable power generation capacity of 53 TW was owned by private persons and farmers, 7% by smaller utilities and only 6.5% by the four large power companies. Concerning PV, the figures were even more impressive—the four large utilities owned only 0.2% of the capacity (Trend Research, 2011).

Despite all bottom-up developments, however, it is clear that large-scale power generation and long-distance transmission will remain important, since half of the electricity is not flowing through the retail system and going directly to large consumers. Their supply will continue to come from large generation units. Moreover, the distribution grids will need more long-distance interconnection for compensating weather-dependent fluctuations. And inter-seasonal storage will probably be most efficiently be provided by large units connected to the transmission system. For all these reasons national systems and markets in Europe are not sufficient anymore. More coordination is required. Incumbent big utilities understand this trend as their opportunity; they try to maintain as many large structures as possible for defending their business model.

In a perspective that focuses on one main coordination level, which for a long time was the national one, increasing decentralisation and increasing scales of exchange seem to be opposed tendencies corresponding to conflicting strategies. Development seems to have reached a point, however, where neither a transition to a unified, centrally managed European electricity market, nor a complete decentralisation to regional electricity supply ("energy autarchy") seem possible or desirable. Also, considering the high pressure for change and the short transition times available, both extremes would need massive state intervention for blocking alternatives, massive investments, or technical breakthroughs. Below and above the national level, new tiers of active balancing and optimisation are needed. Given the complexity of the optimisation tasks and the multitude of interests involved, market mechanisms at each of these echelons and between them seem to be the appropriate instrument. "Regional markets," "market coupling," "multi-level governance," and "subsidiarity" have become important keywords in other discussions on similar kinds of problems, such as regional and transport policies.[49] In the electricity sector, seemingly contradictory trends are leading towards a new kind of multi-level systems of continental size as shown in a schematic representation in Fig. 5.

While a new system logic is growing bottom-up and getting into conflict with the old top-down logic it seems urgent to develop a regulatory framework for a comprehensive multi-layered system aiming at the optimal combination of resources at all scales respecting the principle of subsidiarity. To design such a system in a transparent way, looking at both the technical and the governance aspects, will require considerable effort as different options would have to be compared, sketching transformation paths and testing

[48] "Rekommunalisierung" and "renaissance of municipal utilities" have become a common catchwords (e.g., http://www.ftd.de/unternehmen/handel-dienstleister/:kommunale-stromversorger-die-renaissance-der-stadtwerke/60045429.html). Many cities are buying back the grids on their territory. Calls for action as Klose et al., (2010) till underestimate the challenge.

[49] (Hey and Schleicher-Tappeser, 1998; OECD, 2007, 2011; Schleicher-Tappeser et al., 1998; Schleicher-Tappeser and Institut für Regionale Studien in Europa., 1999).

the robustness of scenarios and strategies. Most present strategic discussions do not yet live up to this challenge.

Against the background of conflicting interests it is understandable that there is a tendency to negotiate ever more complicated patches to the present system and to avoid a transparent comparison of alternatives. None of the presently discussed scenarios takes into account present PV prices and a perspective of growing self-supply.[50]

3.6. Shorter innovation cycles overthrow traditional planning

Electrical, informational, economic and political systems are superposed and interwoven in the public electricity system. Since two key elements of different categories – power generation technologies and customers – are fundamentally changing their roles and behaviours, minor adjustments of the system are probably not sufficient. A fundamental rethinking of the architecture, a shared vision for the medium-term future and timely action in this direction seem to be required before conflicting dynamics may reduce the reliability of the system. Rising prices of grid power and in countries with weak grids also decreasing power quality[51] might accelerate the tendency towards self-supply.

Waiting until problems in distribution grids can be really felt is no solution. When a consistent volume of commercial captive power generation is getting financially compelling without support, politics loses the capacity to control the PV installation rate by adjusting the support level.

As a consequence, the time factor is becoming important in energy policy. Comparing construction times and innovation cycles of old and new generation technologies shows the difficulties of maintaining old structures and procedures—PV and onshore wind have 6 to 10 times shorter cycles.[52] The latest rush on the German PV market shows how rapid the impact of the new technology can be. The PV installations added in December 2011 are capable of producing more than 0.5% of the German electricity consumption.

As in every structural transformation there are winners and losers. Incumbent strong players having strong political influence are trying to slow down change while potential winners of the transformation have difficulties in keeping up in developing appropriate alliances and organisations. Also, as the difficulties of the European solar industries show, it is not clear at all whether those who were the first movers are going to win the game. The political and regulatory management of the transition phase will have a strong influence on the future industrial and economic structures in the energy-related business.

4. Conclusion: Prepare for a turbulent transformation

The semiconductor revolution has reached the energy business. Power generation, power transformation and quality control, as well as the whole management of production, consumption, and exchange are all switching from conventional, basically electromechanical technologies to microelectronic, semiconductor-based, modular and software-controlled technologies. They allow for far more interaction and flexibility, thereby transforming the roles of the persons and institutions involved. The upcoming transformation is in some regards similar to the transition from the railroad to the car, or from the television to the internet.

Trying to predict the speed of disruptive structural change is difficult since new interactions may produce unknown dynamics. In complex systems it is possible to identify tensions and opportunities, but where a tipping point has been reached is often only discoverable ex-post. The new dynamics in the energy business is characterised by new technologies developed by new industry networks, enabling millions of new actors to start to produce power themselves and to interact in new ways with new tools. Self-organisation is starting to play an unprecedented role in a sector which until now has been characterised by relatively hierarchical structures, controlled by a small number of actors with a limited number of choices. Self-organisation and chaos theories may therefore be more adequate to describe the dynamics than the assumptions of conventional planning. The accelerated change of key indicators – which many actors in the political arena have not yet acknowledged – might be an indication that we are approaching a turning point at which new organisational patterns start to spread rapidly. Basic principles for increasing system stability, such as subsidiarity, participation, diversity, and networking may give guidance in phases of turbulent transformation (Schleicher-Tappeser and Strati, 1999). While for years "prudent" or "moderate" public and private policies meant not to bet too much on a desirable but difficult transformation, today prudence means to be prepared for unexpectedly rapid change in a turbulent environment.

Minimising risks gets more important than in the past. From an energy consumer perspective, price and quality risks of public power supply increase, while the opportunities to protect oneself against unwanted developments get more interesting. For those involved in the energy business, the transformation requires more efforts to innovate and adapt. In both cases, the rapidity of change requires proactive initiative. Increasing awareness of the transformation may therefore accelerate the transformation itself. Cooperation in networks may be a promising strategy for facilitating adaptation. System competence is increasingly essential for surviving in turbulent markets. New business models are urgently needed.

The stepwise liberalisation of electricity markets and of international trade, in combination with growing climate change awareness and front-runner support policies for renewable energy have unleashed a highly dynamic development which is about to get uncontrollable with the means of the present regulatory and institutional setting. However, reliable public electricity supply and an effective public grid remain essential for modern industrialised societies. The high probability of accelerated change requires a more rapid development of an appropriate regulatory and institutional framework. It will be important to focus on a lean, transparent structure which can be flexibly adapted, changing only a few key parameters. Complex regulations and market constructions would need too frequent changes in turbulent times and may not be sufficiently transparent for competent democratic control. Most urgent is perhaps the need to formulate and publicly discuss a strategic vision for a multi-level future system which does not lose clarity in technical details.

[50] The EU electricity roadmap 2050 presented in December 2011, assumes (European Commission, 2011b, p. 67) that it would take until 2025 to reach PV system costs corresponding to the real market prices at the end of 2011 (slightly above 2000 EUR/kW). Also prominent proponents of renewable energy have a hard time grasping the rapidly evolving challenges (Schütz and Klusmann, 2011).

[51] In countries with dense grids as Germany decreasing power quality is not to be expected in the next years as distribution grid empowerment for accommodating larger percentages of PV requires efforts which are considerably lower than ordinary grid maintenance (internal calculations of the solar industry association BSW-solar).

[52] Construction times range between weeks and months, compared to several years for conventional plants. Also PV cell and module factories are up and running within 18 months.

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