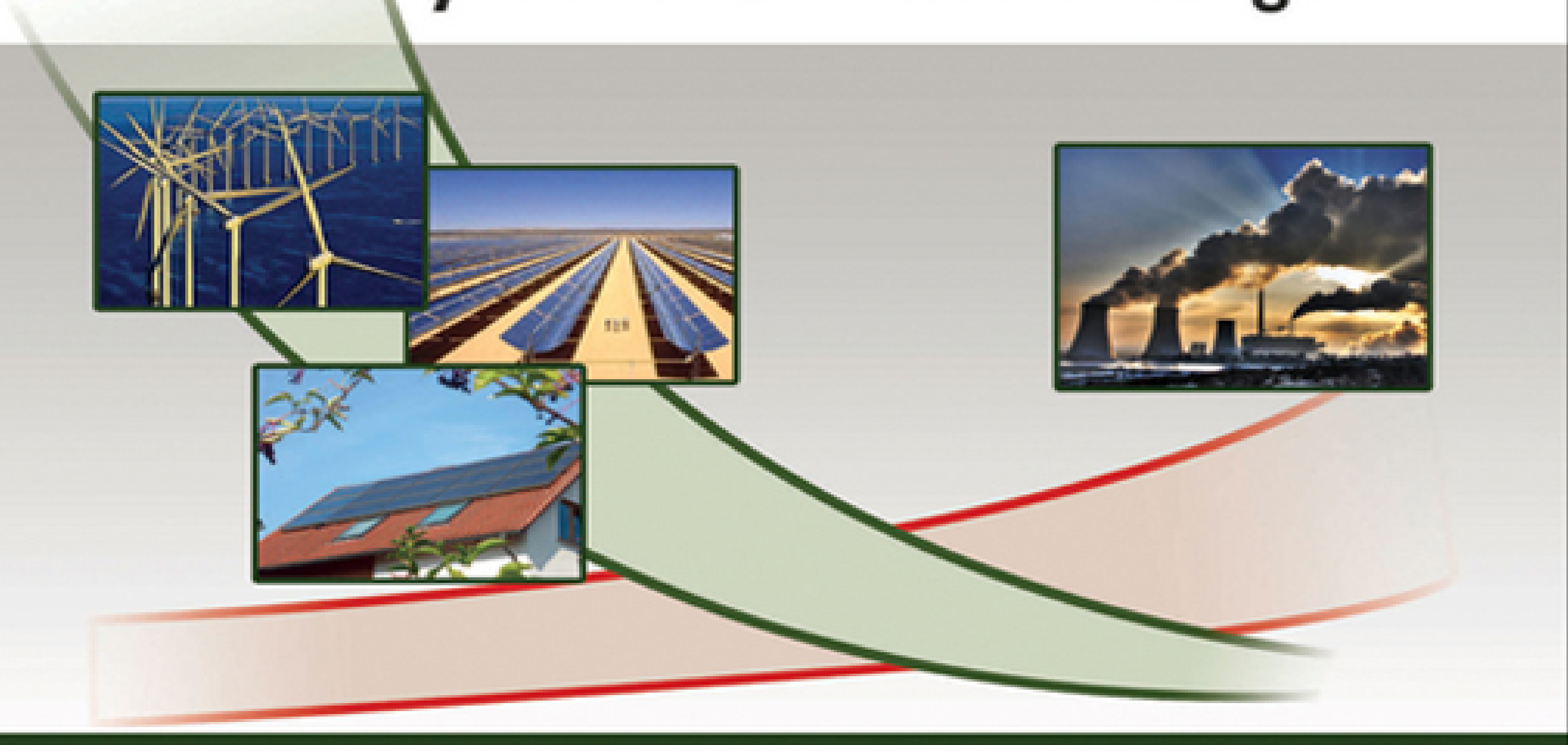
The Economic Competitiveness of Renewable Energy

Pathways To 100% Global Coverage



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Contents

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To our grandson Elija and all other grandchildren around the globe for a future worth living.

Foreword

by Hans-Josef Fell

The time has come for an immediate change to 100% renewable energy sources on a global scale.

Even though renewable energy is currently on everyone's mind, this was not always the case. Or was it? In earlier times renewable energy was also explored. Examples of this are the 1939 Spanish solar stocks and Rudolf Diesel's first diesel engine that ran on cold-squeezed vegetable oil. Also, as early as the 19^{th} century there were tens of thousands of wind energy systems watering agricultural fields. Even Werner von Siemens was convinced that photovoltaics would conquer the world.

However, cheap oil, together with coal and later gas and uranium, increasingly replaced the utilization of renewable energy sources with the following disastrous consequences:

- Huge areas of Japan, White Russia, and Russia are permanently destroyed by radioactivity.
- The global mean temperature has been increasing in – as seen from a history of the earth point of view – a breath taking velocity above 0.8°C compared to the preindustrial level. The consequences are already disastrous: droughts and crop failures, flash floods and rising sea levels, hurricanes, typhoons, and tornados. All in all these have already left a deadly path on a large scale. Global warming has already destroyed lives and resulted in the flow of refugees. The global loss of species has reached an unacceptable level. A further warming up to 2°C – only an additional 1.2°C to the above mentioned value – cannot be tolerated, even if many do not believe it to be reachable.

- The global economy is increasingly being challenged. The state of indebtedness for many is on the rise, not only because of increasing subsidies for fossil energy systems, but also due to the ever-increasing burden of rising fossil energy prices. In one year alone, from 2010 to 2011, the European oil bill increased from 280 to 400 billion US$. And from 2009 to 2010, in order to keep energy prices at a reasonable level for the end users, the global subsidies for fossil energy increased from 312 to 409 billion US$.
- Exceeding the global maximum oil extraction (peak oil) not only leads to a dramatic increase in the price of oil, but also to conflicts over ever diminishing fossil fuel resources. That is why civil wars mainly occur in oil rich countries such as Nigeria, the Sudan, and Venezuela. It is not surprising, therefore, that the oil rich region in the Middle East became a tinderbox that disrupted global peace. The two wars in Iraq, among others, were also fought for oil.
- Even as oil company profits are increasing immeasurably due to rising oil prices, poverty is increasing in the world.

Renewable energy can, and must, make a major contribution towards positive global solutions that address these crises. Renewable energies are decentralized and create jobs that provide earnings for billions of people and not for only a few companies. They relieve energy users from the ever-increasing price of energy raw materials. They make a major contribution to global peace simply because a war will not be fought over sunrays or wind. They are able to stop global warming because they are emission free, or emission neutral in the case of sustainable growth of bioenergy. Together with active carbon sinks, with safely stored atmospheric carbon as “humus” in the upper levels of soil, one can even organize a cooling effect for the earth.

This global change towards 100% renewable energies could evolve quickly if politicians and financial managers create appropriate framework conditions. If private capital was profitably oriented towards renewable energies instead of climate destroying fossil energies, there would be massive investments in them. This was demonstrated in the year 2000 with the feed-in tariff of the renewable Sources Act in Germany. In only one decade employment in the renewable energy sector in Germany increased from 30,000 in 1998 to 380,000 in 2012. This was a crucial contribution to the strong economy of Germany. In the same decade there was an increase for PV to the electricity supply from 0.01 to 8% in the industrialized country of Bavaria, with a still-growing investment velocity. What is possible in Bavaria is also feasible globally. This is even more so because solar electricity as well as electricity from wind and hydropower costs less to produce today compared with new conventional power plants.

The industrial revolution for information technology was initiated at the California universities of Stanford and UC Davis. In less than 30 years personal computers have conquered the world, even though in 1988 the head of IBM still believed that there would be no personal computers at all. At the same universities a global plan was developed which showed that a complete change of the global energy supply to 100% renewable energies by the year 2030 is industrially and technologically feasible. Furthermore, scientists Jacobsen and DeLucchi demonstrated that this would be considerably less expensive compared to persisting with the conventional energy supply.

There will be losers in this process such as the conventional economy based on oil, gas, coal, and nuclear energy. However, the global community should no longer consider their economic interests. The fight against poverty, the empowerment of economic development instead of state bankruptcies, and the securement of global peace and effective climate protection are much more important than the profit interests of the oil, nuclear, and coal industries. A global change towards 100% renewable energies is possible, giving mankind the chance to quickly change any ruinous developments for the better.

Former Member of the German Parliament,
Former spokesperson for energy and technology for the party
“Bündnis 90 / Die Grünen”
Vice president of Eurosolar
December 2013

Preface

It is the pretension of this book to give a comprehensive picture of today's energy world, to describe the potential for energy savings which can be achieved and to get an understanding of technology development which will lead to a 100% renewably powered world as the most likely situation. This is based on the long-term economic and ecological superiority of renewables over traditional energy sources. It is the combination of these topics which makes the book unique. This abstract can also be used by the reader to make his or her own sequence for the 11 chapters according to personal preference – although for those who are no experts in the field it is useful to follow the given order.

The **Introduction (Chapter 1)** starts with a description of a general phenomenon, namely the fundamental changes taking place in the world we are living in today, not only in the area of energy but also the way in which we communicate and exchange information across the globe. It critically analyzes what the general public is told by incumbent political and industrial institutions. It is this change which lays the ground for a major alteration including in how to use and produce our daily energy - from centralized systems back to municipal and even individual levels. Environmental concerns and the growing awareness about the finiteness of traditional and affordable primary energy (fossil and nuclear) will accelerate this change.

The **Analysis of Today's Energy Situation (Chapter 2)** first describes basic energy terms for those who are not experts in this field. Today's global energy situation is analyzed in form of primary (140 PWh), secondary (90 PWh) and end user energy. The various energy sectors – mobility, industry and private/office/SMEs (small and medium enterprises) – where the secondary energy is used, are specified.

When analyzing the potential of the various exhaustible energy sources and simply comparing the total sum to our current energy usage per year, it is tempting to simply divide these two numbers. The result varies – depending on how many unconventional sources are considered – between many centuries and up to two millennia. It is emphasized that a much more differentiated look must be taken.

There are major challenges for fossil energy: finiteness leading to “peak oil and gas” in the foreseeable future will result in increasing prices and CO_2-emissions, which either will add significantly to the generation cost (if carbon capture and storage can be realized) or will cause irresponsible temperature increases due to Greenhouse Gas emissions. A journey through the history of our earth dramatically outlines what we are currently doing by passing the CO_2-concentration of 400 ppm due to burning fossil fuels. Such a level was only seen millions of years ago. Accelerating factors of global warming like the melting of glaciers and permafrost thawing are also described and add to the imperative: we must ACT NOW!

The problems with nuclear technology for all reactor types, fission, fast-breeder and fusion are detailed and it is shown that these problems simply add to the inferiority of this type of electricity production; an inferiority which already stems from their higher generation cost compared to renewables – assuming no subsidies for either technology.

The **Importance of Efficiency Measures (Chapter 3)** has nothing to do with renewable technologies but the measures described will help a lot to achieve a 100% renewable contribution sooner rather than later. The importance for the general public to understand that efficiency measures will not decrease their comfort of living but will give them the "same quality of life with much less energy" is highlighted. In conjunction with renewables as secondary energy provider this will even change to a "better quality of life with much less energy".

Emphasis is placed on the fact that many energy efficient products have a higher price when purchased compared to older ones which, however, is more than offset, when the total life cycle cost or levelized cost of service is considered as shown through the example of future lighting. The superiority of electro mobility will only evolve if electricity is provided by renewable technologies. The significant savings in heating and cooling energy for houses will be seen with well insulated houses in the future, which will in parallel lead to less solar thermal appliances. As a summary, the secondary energy which would be required today with the available energy efficiency measures (~45 PWh) within the various sectors is given. A recommendation to politicians is provided on how best to accelerate the introduction of energy efficient products, namely through reasonable support for the new technologies and not simply by banning the old ones.

An **Overview of the Most Important Renewable Energy Technologies (Chapter 4)** starts with an outline of the huge potential of renewable energy resources. The outstanding offering from solar irradiation exploited by three technologies – decentralized PV, centralized concentrated PV and solar thermal electricity (or concentrated solar power, CSP) as well as solar thermal low temperature – is highlighted. Simply considering land use and near-shore coastal regions for wind off-shore ("technical potential"), we can provide 880 times today's secondary energy through renewable energy and when taking today's technologies and feasible areas ("sustainable potential"), ~35 times today's secondary energy could be provided (and 21 times the future secondary energy needs for our 100% renewably powered world).

The historical developments of technology and market are detailed for wind energy as well as for solar thermal collectors and concentrators. Readers will understand why wind turbines are getting higher and higher to make best use of the wind conditions at a given site. An overview of PV and other renewables (hydro, geothermal, wave and tidal) is also given.

The **PV Market Development (Chapter 5)** starts with a topic which is addressed to economists, in particular to liberal ones. When it comes to the question of whether support schemes are useful or whether only free market mechanisms should decide on certain technology developments it is advisable to differentiate between strategic goods – such as electricity production, transportation – and consumer goods – like mobile phones or televisions. It is shown that while for the second group the free market mechanism is the right instrument, this is fundamentally different for the strategic goods. When it comes to the question of whether support for a technology should be organized through market pull or technology push, the clear answer from an industrial point of view is through market pull.

The development of a multitude of different customer needs for PV products and the associated market volume is discussed from the 1970s until today. The unimaginable average market growth of more than 50% per year in the first decade of this century was only possible due to the support scheme in form of the Feed-in tariff, where renewable technologies went along with a long-term payment (typically 20 years) for all produced electricity based on the respective cost plus a positive margin. Based on the ideas by Wolf von Fabeck and municipal experience in Switzerland, it was Hans-Josef Fell and a good number of supporters who first got it politically up and running in Germany, after which it spread out into more than 60 countries worldwide. The total budget for these payments (minus the stock exchange value) can be seen as an investment by society and it is shown that the associated Net Present Value is clearly positive with conservative assumptions. Even if there is considerable outcry over the many billions spent on this investment, it obviously pays off when analyzed over the long-term payment period. The fact is that after this time period our children will benefit from a “golden age” in which electricity is produced at marginal cost with depreciated PV systems throughout their life-time which is significantly longer compared to the typically 20 year’s payment time period.

In times of high annual growth as mentioned above, some bottle-necks along the value chain (e.g. poly silicon) appeared, resulting in an increase in prices. This was taken as a signal to invest in additional production capacities all along the value chain. With clear industry political goals coupled with a number of clever entrepreneurs it was Asia, particularly China which increased its global share in PV module production from about 5% in 2005 to 60% in 2012. Unfortunately the capacity increase outgrew the market volume which resulted in about 100% overcapacity in 2012. As in every industry the consequence is now a shake-out of production companies associated with (too) low product prices and deep red numbers on the balance sheet. The flipside of this situation is that it allows new markets to establish themselves which would not have been realistically possible only a few years ago. After this consolidation period and a further market growth we will see a new wave of production facilities which, with new ideas from the R&D-institutes, will enable cost numbers which are low enough to achieve positive margins at today’s prices. In 2013 we are in a time where we clearly foresee the end of the running Feed-in tariff program in only a few years, which leads to the necessity to install a new market design for the future increased levels of renewable electricity including the procedure how renewable electricity is traded on the stock exchange. The development of electricity storage, Demand Side Management, smart grids and virtual power stations is described.

The **PV Value Chain and Technology (Chapter 6)** summarizes the various PV technologies c-Si wafer and Thin-Film in greater detail, but also describes concentrated PV, Dye solar cells and organic devices. Besides modules, the additional components for a complete PV system such as inverters and BOS (Balance Of Systems) components are also dealt with. Based on a number of examples an important observation is described: the power of continuous development and economy of scale versus breakthrough technologies to decrease production cost is most often underestimated.

The **Astonishing Predictive Power of Price Experience Curves (Chapter 7)** shows impressively what even research and industry people from the same technology sector could often not believe. Such curves plot the cumulated volume of a particular product versus the respective price in a double logarithmic scale. From the slope one determines the %-change in price for each doubling of cumulative volume. With the example of DRAM semiconductor devices it is demonstrated that all people strongly believed in the 1970s/1980s that the slope was horizontal – i.e. no further price decrease – after the 1990s. Yet 20 years later we are still running down this same graph. Similarly for Flat Panel Displays such a development has been on-going since the 1990s.

Emphasis is placed on the fact that while big and centralized technologies have more of a project character for specific regions, small and mass produced components which are globally produced and internationally traded have a high probability of reaching significant cost and price reductions. Examples of centralized technologies are power stations; examples of mass produced components are PV solar modules, batteries and fuel cells.

The Price Experience Curve for solar modules (c-Si and Thin-Film) is shown as well as for inverters and by analogy to the examples given before, there is sound reason to believe in a further continuation of falling prices. Deviations from the slope can be explained by e.g. product shortage for prices above and overcapacity for prices below the Price Experience Curve.

The **Future Technology Development (Chapter 8)** is discussed for all renewable technologies. The potential price development is based on the respective Price Experience Curve

For **Future Energy Projections – The 150 PW-Hour Challenge (Chapter 9)**, some well-known projections from the IEA and Greenpeace are shown for reference. The market development for the various renewables and their potential market share are described in some detail. Reasoning for a simple split to cover the required 150 PWh of energy for future secondary energy is explained: decentralized PV, centralized concentrated PV and solar thermal electricity systems, decentralized low temperature heat, wind energy and the rest of all other renewables provide 20% each, or 30 PWh of energy.

Realizing that if renewables will take over the 100% energy supply there will be huge industries for all technologies and therefore a great opportunity for all economic regions to grow a sizable industry for this future. Individual companies should be encouraged to make an extra effort to be in that business. With the example of PV it is estimated that the annual overall turnover in the 2040s will be comparable to the global annual turnover for the automobile industry.

The **Likelihood and Timeline for a World Powered by 100% Renewables (Chapter 10)** deals with the potential development. While some years ago the need for a global network in form of a worldwide super grid was seen as an elegant solution, a new model may emerge: local autonomy for the decentralized private and SME sector and relocation of the energy intensive industries, which need power and process heat, close to places which cost effectively deliver energy from the centralized hydro, (concentrated) PV and (off-shore) wind parks (sometimes it may be more cost effective to link power intensive industries via transmission lines to the big renewable power stations).

In **Conclusion: The 100% Renewable Energy Puzzle (Chapter 11)** summarizes the findings and discussions from this book in form of a 3 by 3 element puzzle. The limit of a 2°C temperature increase can only be accomplished if we shift all fossil power stations to renewables as quickly as possible. Nuclear is not a viable alternative for safety and cost reasons. Driven by mass produced products like solar modules, batteries and other devices which are important for the future 100% renewable world the cost and price decrease will demonstrate the economic superiority of renewables over traditional fossil and nuclear technologies by the 2020s at the latest. Once this is recognized by the financial community there will be a substantial re-allocation of huge investment money, away from traditional technologies and a steady move towards the 100% renewably powered world.

Acknowledgements

This book would never had been possible without the continued support and the silent agreement from my wife Anneliese not to pursue her own career but to care for the family and guide two great kids, Tobias and Elisabeth, from birth through childhood and school into their adult age.

Only this allowed me to devote my time – not only during business hours – to growing a company (ASE – Applied Solar Energy) from scratch to one of the five largest cell and module producers in the early years of the new millennium. My thanks go out to all who supported me in those years, from colleagues and employees to shareholder individuals like Heinz-Werner Binzel, who believed in this new business and supported it in an environment where one would not always have expected it. My thanks go out to all customers who dared to buy the new products in those early days. Equally vital was the cooperation with machine builders and scientists, at which point I wish to highlight Prof. Rudolf Hezel from ISFH and Prof. Joachim Luther from the Fraunhofer-ISE.

At the same time, it was necessary to grow a market with the engagement of colleagues from other companies, who in the end turned out to become good friends, like Hubert Aulich, Tapio Alvesalo, Günther Cramer, Georg Salvamoser and many others in associations like BSW Solar and EPIA, who convinced and supported politicians in creating market support programs – the latter group is best represented by Hans-Josef Fell, to whom I am also grateful for the Foreword of this book. I also enjoyed the cooperation with other renewable associations which gave me the chance to get a better understanding of the other renewable technologies –

this was a prerequisite for delving deeper into these products and into the important role which they play.

Not being a native speaker, I very much enjoyed how my German English was shaped into English English by Jenny Taylor. Last but not least it was Martin Scrivener who convinced me to put this information into a book after a plenary talk I gave in Chicago at the start of a big international scientific conference back in spring 2011(!) on this very subject. Had I known from the start how much pain it would take to bring this to a successful conclusion, I do not know whether I would have even started. But in the end I found it to be worthwhile and I thank Martin for his continued encouragement which helped me, together with the constructive comments from my students on the topics, to complete this book.

List of Abbreviations

Abbreviation	Full name (translation or additional information)
BAPV	Building Added Photovoltaics (modules attached to existing buildings)
BIPV	Building Integrated Photovoltaics (modules as integral part of buildings)
BSW-Solar	Bundesverband Solarwirtschaft (German Solar Economy Association)
BMU	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
CEO	Chief Executive Officer (Head of management board of a company)
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage (also called CSS = carbon sequestration and storage)
CHP	Combined Heat & Power
DEEM	Direct Energy Equivalent Method
DSO	Distribution System Operator (Medium and low Voltage)
EEC	Energie Einspeise Gesetz (Renewable Energy Sources Act, FiT in Germany)
EPIA	European Photovoltaic Industry Association
EREC	European Renewable Energy Council (umbrella organization of all major European renewable technology associations)
FiT	Feed-in Tariff
GHG	Green House Gases (CO_2, CH_4, water vapor etc.)
IEA	International Energy Agency
IPCC	International Panel on Climate Change
OECD	Organization for Economic Co-operation and Development
PE	Primary Energy (Energy embodied in natural resources)
PV	Photo Voltaic
P2G	Power to Gas ((renewable) electricity → Hydrogen by electrolysis + CO_2 → CH_4)
R&D	Research and Development
RE(S)	Renewable Energy (systems)

SE	Secondary Energy (transformed Primary Energy, also called final Energy, which reaches the final consumer’s door plus energy used in the energy sector itself, e.g. transmission losses for electricity)
SKE	Stein Kohle Einheit (hard coal equivalent)
SME	Small and Medium Enterprises
TSO	Transmission System Operator (High Voltage)
UNEP	United Nations Environment Program
WBGU	Wissenschaftlicher Beirat der deutschen Bundesregierung für globale Umweltveränderungen (Advisory Board to the German Government on Global Change to the Environment)
WEO	World Energy Outlook (by IEA)
WMO	World Meteorological Organization
WTO	World Trade Organization

Chapter 1

Introduction

1.1 The Changing World

We are living in a world of fundamental changes: since industrialization started with the steam engine in the 1770s by James Watt we have experienced phenomenal growth in many areas. Let’s take the global population as an example, which grew from 1 billion in 1800 to 3 billion in 1960 and to more than 7 billion today. Energy consumption grew from 3 PWh (10^{12} kWh) in the mid 1800 to ~150 PWh today, CO_2 emissions grew from ~0.2 Gt (billion tons) in early 1800 to ~30 Gt (fossil and other) today. The mentioned increases between 1800 and today are an impressive factor of ~7, ~50 and ~150 for the global population, energy use and CO_2 emissions, respectively.

Until the 1970s, there was only little concern over whether there should be any worries about the finiteness of resources. This changed after the first serious publication on energy and material scarcity in form of the report “Limits to growth” by the Club of Rome in 1972 [1-1] and, coincidentally, the first oil price shock in 1973. Until recently, only concerned individuals and dedicated organizations highlighted the finiteness of traditional primary energy sources – now the IEA (International Energy Agency) points to the same fact in their latest World Energy Outlook. An atmosphere of change has evolved, due to concerns over climate change which will ultimately have a dramatic impact on the human population and which is caused by increased CO_2 concentration mainly by burning fossil sources to produce electricity.

What are often called the “residual” risks associated with nuclear power should be renamed (as in Germany) “intolerable” risks as has been demonstrated again in Fukushima but also due to not manageable potential terrorist actions. The unsolved storage issue of spent fuel for nuclear reactors is of additional concern. After all, it is also the increasing cost figures which do not even contain insurance numbers as no insurance company worldwide is willing to take on the associated risk.

Of course, current industries which have established themselves well in the old environment do not like such developments and are trying to find ways to at least prolong the business as usual scenario. Together with their closely attached supporters from politics and industry they are instead trying to push for solutions which they themselves could most easily realize: CCS (Carbon Capture and Storage) for fossil use and new nuclear reactor types like Fast Breeder and Fusion. There is, however, one very clear fact: you cannot stop a better product whose time has come to replace the old one. And those who are not willing to adapt will not survive – as will also happen in the energy sector. In contrast, a multitude of new players entering the energy field very often underestimate the challenges – at least time-wise – which are linked to the introduction of more and more decentralized renewables, new customer behavior, energy storage, energy efficiency measures and much more.

The large scale introduction of renewable energies also needs better communication at the local level since they demand much stronger decentralized solutions. This process of decentralization has already taken place in many industries. Let us take a look to some examples from the past with first, the introduction of personal computers in the