WCRE
World Council for Renewable Energy
c/o EUROSOLAR e.V.
Kaiser-Friedrich-Str. 11
53113 Bonn / Germany
Phone: +49 (228) 36 23 73
Fax: +49 (228) 36 12 13
e-Mail: info@wcre.org
Internet: www.wcre.org

A PV Roadmap for Europe

Wolfgang PALZ
Chairman, World Council for Renewable Energy, Paris/Brussels
E-mail: w@palz.be

Abstract: In this paper a new PV roadmap is proposed for the European Union, the EU25. It assumes, as a baseline, to implement fully the maximum potential of PV integration in the building sector by 2050. That over-all potential is evaluated at 442 GW installed capacity; half of it, 121 GW, could be realized between 2035 and 2040. Energy autonomy of the whole building sector can be achieved in line with a general EU policy of "distributed generation". It has to take into account the particular climatic constraints which affect large parts of Europe, inter alia a lack of much solar irradiation in the winter months. To this end it is proposed to combine PV with solar hot water systems for maximum use in the summer - and co-generation powered by car engines from the automobile industry, in particular those derived from the "Prius" car which combines a fuel engine with a battery. The engines should be fueled primarily by bio-alcohols, but other options like bio-oils or bio-gas are equally valid - they would provide most of the needs for electricity and heat in the winter months.
The strategy relies fully on a combination and integration of devices and products for which a mass market exists today already. It avoids speculating on new developments to come and is ready for implementation, now.

Key Words: PV in Buildings, Co-generation, Bio-fuels

1 Introduction

The global energy sector has to cope with two pressing problems, declining fossil and nuclear fuel reserves and climate change due to man-made GHG emissions, and in particular those from the conventional energy consumption patterns. Influential political quarters under the leadership of the established energy industry and the "neocons" in America are known for their reluctance or blunt refusal to recognize the evidence of the dangers involved or at least to draw the right conclusions for action. But eventually the international markets are calling the financial and political powers to order. An oil price above 60 $ a barrel and a carbon exchange rate of 30 $ a tonne can no more be ignored.

And the world community of energy and climate experts has a clear message. "G8 governments (should) establish national renewable portfolio standards to generate at least 25% of electricity from renewable energy sources by 2025, with higher targets needed by some governments" was a recommendation of the International Climate Change Taskforce from the beginning of this year, to mention just one of the many such initiatives which exist.

PV is considered rightly by many as the royal route among the renewable energies. But it is widely recognized that its development cannot be left to the markets alone. Financial promotion and political regulations are necessary until the time PV becomes commercially competitive in conventional power networks (in most off-grid applications it is already today). This explains the need for national and international strategies and implementation plans.

2 PV as Part of a Comprehensive Renewable Energy Strategy

PV will eventually be part of a mix of all the various kinds of Renewable Energy markets the local deployment of which will depend upon the particular climate and policy conditions. They all have to find their place in that mix, to various degrees though, depending on their cost prospects and actual promises.

In the transport sector, bio-fuels will be the preferred option, in line with the mass-market developments which are by now under way in Brazil and the USA.

For the heating requirements, biomass in its various forms will displace progressively the fossil fuels, be it as pellets, chips, woody briquettes, charcoal, biogas or bio-fuel liquids. And next to biomass heating, passive and active solar use will become very important. Other options for heating with renewable sources are inter alia geothermal waters for district heating, sometimes upgraded with heat pumps.

Unlike energy for transport and heating, electricity generation and provision is very much centralized today. But the understanding of the need for decentralization is making progress in the political quarters. Much of the power production can in future be moved to the regions or the neighbourhoods of use. Apart from the political arguments, there are also the tremendous efficiency gains through co-generation which are good reasons to go for smaller production close to the demand centers. Bio-electricity is an example in case where power production should wherever possible be associated with proper use of the derived heat.

Decentralized production fits naturally with wind power, geothermal power, and PV, including the ground-mounted arrays. In Germany, ground-mounted PV plants in the 10 MW power range are currently promoted to some extend, namely on former military and industrial grounds. This segment may become of particular interest for PV arrays which are following the sun – namely in Northern Europe where the summer sun comes in wide circles over the horizon. Sun tracking is needed for concentrators anyway; they belong as a rule also to the category of ground-mounted arrays.

The new PV Roadmap which is proposed in this paper sets its priority on building-integrated PV on the largest possible scale. PV fits indeed best on buildings of the tertiary incl. the domestic sector for many reasons. On the building envelopes, the areas for installation are already freely available and allow for dual use. Consequently, it is easier to compete with the electricity tariffs charged to the buildings than with the tariffs offered by the operators of the high-voltage grids, leaving alone all those transmission losses. PV is one of the keys to make future buildings energy efficient and pleasant to live in. As the building sector is the single-biggest energy consumer, the energy impact of PV has its future mainly there.

3 Towards a PV Roadmap for the EU

3.1 Stocktaking of International PV Goals and Strategies

The only official target for PV market implementation in the EU is the one put forward by the EU Commission to the EU Council and Parliament as part of its White Paper on Renewable Energy in November 1997. It calls for an over-all PV capacity of **3 GW** to be installed by 2010. This goal had been "inspired" by the author on the assumption of an average 10 W per capita [1]. Originally it was indeed for 3.7 GW as the EU15 of that time had a population of 375 mio people. Following this logic, the goal should have been up graded to 4.5 GW since the EU15 has meanwhile become the EU25 with 450 mio people. Since its inception, a total installed capacity of 1 GW was actually achieved at the end of 2004.

Japan has a similar objective of **4.8 GW** domestic installation of PV by 2010 and has also passed the 1 GW mark already. It is generally accepted today that both the EU25 and Japan will meet their 2010 objectives. On a per capita basis, Japan will do much better than the EU25 because its population is smaller by a factor of 3.5. Only Germany, the European leader in PV, will have a comparable PV market penetration on a per capita basis, too.

As we are coming nearer to the year 2010, a number of initiatives have already been issued for possible PV implementation at the time beyond. DG Research of the EU Commission has issued this year a report with the title "A Vision for PV Technology" [2]. This report proposes a goal of **200 GW** in the EU, and even 5 times as much globally, by 2030. The European PV Industry Association came out in May 2004 with an EPIA roadmap and a possible scenario with **41 GW** PV installed in Europe plus 30 GW exported by 2020 [3]. Later, in the same year, EPIA published with Greenpeace the report "Solar Generation, Solar Electricity for over 1 Billion People and 2 Million Jobs by 2020" [4]. The report assumes a world-wide installed PV capacity of **205 GW** by 2020; it has no specific target for the EU but only for Germany (18.5 GW). All these EU roadmaps are not totally consistent with each other. Interesting enough, it is the one of PV-TRAC, under the Commission auspices, which has the most aggressive targets. All reports seem to have in common that they are not very explicit on the way these goals have been constructed.

As far as the U.S. is concerned, one should mention the roadmap from SEIA, the Solar Energy Industry Association, published in September 2004 [5]. The U.S. goal for 2030 is a PV capacity of **200 GW** at an electricity price of 3.8 cents/kWh, or expressed otherwise "Solar provides half of all new U.S. generation capacity by 2025". U.S. scenarios cannot be compared directly with those for Europe as the "solar climates" are different and also the consumption patterns. Due to air-conditioning needs the U.S. has a big summer consumption which goes parallel to the solar production. In the EU, electricity consumption is on average by 20% higher in winter than in summer, it is anti-cyclic to solar irradiation and production.

3.2 Approach and Criteria for Developing a New PV Roadmap for Europe

Unlike 10 or 15 years ago, Europe has already a relevant basis of PV achievements on which to build future market scenarios of some credibility: "Wishful thinking" alone is not adequate. But these achievements are not spread evenly across Europe as a whole. Germany alone has now, by mid 2005, a total PV capacity of 1 GW (peak) installed in the country. As it were, its PV capacity represents 80% of the total in EU25, i.e. the other 24 Member States together represent only a meager 20%. Otherwise expressed, it is the strong market base in Germany which can justify an extrapolation exercise to the future. For the whole EU25, such an extrapolation could well be hazardous.

Germany is also interesting as a showcase as it is the most populous country in the EU25 – 82 mio people or 18% of the EU total live currently there. Furthermore, Germany is Europe's leading economy. Of relevance for our study is also the fact that Germany has developed a certain "ecological culture". Not only is a large majority in the polls in favour of an aggressive promotion of the renewable energies, strong national policies have already shown extraordinary results which are rather unexpected for a densely populated country with modest solar, wind, and other renewable resources: Germany is not only EU market leader in PV, but also for solar water heaters, wind power generation, bio-diesel, and agricultural bio-gas. **Consequently, a first element of the approach taken in the present study is to take Germany as a model case, extrapolating from its solid base of 1 GW PV installed and 0.4 GW or 5 W/capita added in one single year (2004).** The results can later be extended to the EU25 by applying a factor of 5.5 which corresponds to the EU's over- all population with respect to Germany's share.

A second element of our approach consists in identifying, as far as possible, the maximum potential market in the targeted sector, i.e. the building market with integrated PV. On the assumption that the global problems of waning fuel resources and climate degradation will become more pressing all the time, the study demands a 100% implementation of the potential market by 2050. If that could eventually be achieved, the PV market development from today till 2050 would follow an S-curve pattern.

Thirdly and finally, we will refrain from speculating greatly on new technologies to come. R&D is most important for increasing efficiency, reliability and to bring costs down, but scenarios built on devices which have not yet achieved maturity are most questionable. As a "baseline", we will exclusively count on technologies and devices which are in the mass market already. For PV in particular we take very conventional technologies for which the cost prospects were analyzed already years ago very thoroughly. New discoveries will later be welcome to improve the scenarios further.

It should be made clear that this new roadmap is only one scenario of the many one can develop. The figures which are proposed are very approximate by nature. But it is felt that it is a realistic description of a possible mainstream route for PV development in Europe. **It is one of the goals of this study to increase credibility of the fact that PV has eventually a great future in Europe, too, and not only in the "solar belts".**

3.3 The Concept

The full potential of PV in the built environment can best be achieved when PV makes an essential contribution to the buildings' self sufficiency in energy terms. In the long run, PV must play its rôle mostly in energy-autonomous buildings rather than as add-on devices in the grid-connected systems of today's markets. However, as a rule, buildings will not be able to rely exclusively on PV for all their electricity needs. That would rather be the exception. The reason is that PV deployment in Europe has to cope with the fact that the solar resource is poor in the winter, particularly so in its central and northern parts [6] but also to some extend in the south. The solar radiation is approximately evenly distributed over all parts of Europe in the summer with 5 +/-1 kWh/m^2.day on collector surfaces which are inclined at the latitude angle [7]. In the winter the figures come down to 1.2 kWh or less in the centre and the north and 3 kWh and more in the south of Europe.

It would be unrealistic to overcome that winter deficiency of the resource by seasonal battery storage. The cost and complexity would be tremendous. The obvious solution is instead co-generation.

We propose to employ engines derived from the automobile industry without waiting for fuel cells or other exotic engine developments eventually coming "out of the woods" to the mass markets. Car motors have been built in the hundreds of millions and their overall power is today a multiple of the total capacity of all electric production plants counted together. The know-how is tremendous in this industry. Those engines are efficient, reliable and cheap. One which is particularly attractive for our purpose is the hybrid power system of Toyota's Prius. The Prius has been elected European car of the year 2005.

The hybrid engine of the Prius car can, when applied in the building sector, provide power and heat for energy autonomy. Thanks to its battery it combines ideally with PV. Eventually, the engine should be fueled with bio-alcohol (alternate versions on the basis of bio-oils or bio-gas are possible). Only in this way can the system become sustainable in all its parts relative to the global problems ahead in terms of limitation of conventional resources and climate change.

Consequently, we propose the following concept of this Roadmap aiming at full energy autonomy of all buildings:

- A car engine for co-generation of power and heat to be fueled by bio-fuels. The system will primarily provide the building's energy needs in the winter months and partly in spring and autumn. The system will run at maximum efficiency over the year. It has indeed not to be operated in the warm months when no external heat is needed. In those periods the solar collectors take over, PV for the electricity charges and heat collectors for tap water.

- A PV system associated with battery storage for a few days. It should cover the electricity needs in the summer months and partly in the intermediate seasons.
- Solar thermal collectors and the usual storage, for hot water consumption.

4 The Model of Germany

Table 1 shows a summary of Germany's over-all energy consumption breakdowns. It is based on a comprehensive analysis prepared and published by Eurostat for the EU15 Member Countries [8]. The data are for 1998; but as they did not change much since then – except for wind energy which contibutes now already 6% to all of Germany's electricity consumption - they remain valid for our analysis.

	All (mio toe)	**Electr** (TWh)
Gross Energy Consumption	343 (1)	530 (2)
Total Final Energy Demand	255	466 (3)
Non- Energy Use (chem.)	25	
Energy Use	224	466
Industry	57	208
Transport	65	16
Tertiary	101	**242**
Domestic	68	130

mio toe = million tonnes of oil equivalent

(1) Including "gross" nuclear, excluding hydro, wind, PV…
(2) Including nuclear, excluding hydro, wind, PV...
(3) Including nuclear, hydro, wind, PV. Excluding 85 TWh for auto-consumption and transmission losses

Table 1 Summary of Germany's energy consumption

35% of gross energy consumption goes into electricity production. Half of the net electricity, exactly 52%, is taken by the tertiary sector. **For our analysis we assume that 50% of the power demand in the tertiary sector can eventually be met with PV.** This takes into account the fact that PV's share can only be marginal in winter time but maximum in the summer.

Consequently, the maximum PV market potential turns out to be half of 242 TWh or 121 TWh. This corresponds to 1.5 MWh per capita and year. Now we assume that electricity consumption would be reduced to 2/3 of this value by 2050, the time when most of the PV potential would have been realized. The EU Commission's Green Paper on Energy Efficiency [9] mentions a 20% energy savings potential in EU 25 by 2020. It is true to say that in the communication sector, the new digital technology will indeed do with less electric energy than the conventional analogue one. For all appliances like frigerators, washing machines etc., the labeling imposed by the EU for energy efficiency is already having a great effect to reduce electric consumption in the domestic sector. Power needs for lighting which is also very important in offices and other non-domestic buildings will come down, too, as new technologies such as LED are becoming available. In a country like Germany where households and offices are already saturated to a high degree with modern appliances, all these perspectives should indeed make it possible to save eventually on the 2050 horizon at least 1/3 of the electricity which is consumed today in the tertiary sector.

Keeping in mind these perspectives, we assume for 2050 a yearly per capita consumption in the tertiary sector of 1 MWh to be covered by PV, a 50% of the 160 TWh total for Germany by that time.

An over-all PV capacity of 80 GW or 1 kW (peak) per head will under these assumptions be the potential for Germany. This capacity would be spread between the domestic sector to 2/3 and the rest of the building sector – offices, schools, etc – to 1/3. This share can at least be seen on the current repartition of charges in Table 1. A household of 3 would then have 2 kW or some 15 m² of PV collectors on its own dwelling and the rest shared on public buildings.

For these findings it is further assumed that on a yearly average, a 1 kW PV generator will deliver 1000 kWh. For Germany this is on the high side since current systems produce rather between 800 and 900 kWh/kW only. But for Europe as a whole, the 1000 kWh look realistic.

Germany has currently, by mid 2005, approximately 14 W/head installed. Even more significant is the fact that in one single year 5 W/head were added. To realise the target of 1000 W/head PV between now and 2050, one would have to install on average 22 W/head.year. This does not look unrealistic, never mind that the German market will not be booming the next few years as one could expect from a very strong demand because we have the supply problem for silicon feedstock. Seen from a long-term perspective this is a momentary phenomena only.

5 The EU Roadmap

5.1 Description

Generalizing the scenario for Germany with 82 million people to EU25 with 450 million will then result in a total PV capacity of 442 GW by 2050, i.e. 5.5 times the German capacity of 80 GW. It is anticipated that full implementation by 2050 would follow an S-shape market development as shown schematically in Figure 1. It is understood that in the next few years, market development will remain relatively flat because outside Germany, the political and practical market "credentials" are not yet in place today. This is why we think that half of the maximum capacity would not yet be installed around 2028, i.e.

half way between now and 2050, but rather 10 years later, e.g. **220 GW by 2038**, when the market development got in full swing. On the other hand, there will be no real saturation of the market when the goals are reached by 2050 or there about, given that there will always be a big demand for replacement and new buildings – the building stock changes by 1 to 3% every year.

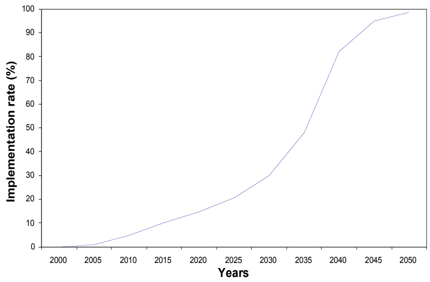

Figure 1 A scenario for PV market implementation in the EU by 2050

The PV array on the building will be complemented by a solar heating system for tap water. A co-generation system consisting of a car engine and a battery like on the Prius car will be available for the periods of insufficient solar irradiation. The engine will be fueled with bio-alcohols that can be distributed the same way the heating oils of fossil origin are distributed today. Alternatively, bio-gas will be distributed instead of the natural gas which comes through the pipelines today. The power of the engine is not critical since the charging time of the storage battery is a free parameter. When the engine is powerful – which is normally the case for a car motor when compared to the peak demand of a single house – the charging time of the battery will just be shorter.

Seen on a macro scale, full implementation of the PV market in Europe the way it is proposed in our scenario, will make the over-all power generation and consumption system a lot more efficient: (1) it will get rid of a major part of the emissions in terms of GHG and other pollutants associated with the large conventional power plants of today; (2) it will eliminate the heat rejection of those power plants into the water – leaving alone the problem of water availability for that purpose - and the air; between 2/3 and 1/3 of the fuel input is wasted, depending if it is a nuclear, oil, or a coal-fueled plant which have the highest heat rejections, or a Combined-Cycle plant which have the lowest; (3) most of the 18% losses for autoconsumption and for power transmission as accounted for in the German case in Table 1 will be avoided.

5.2 A Roadmap ready for immediate action

It is important to note that all components of the power system anticipated in our scenario are presently available in the mass markets.

Global PV module production in the industry has passed the significant mark of 1 GW per year. PV modules are certified industrial products which are manufactured nowadays in large automated plants of up to 300 MW capacity/year.

Solar hot water (SHS) systems have also become products of the mass market. 1.7 million M² was installed in the EU in 2004 corresponding to 1 GW thermal power [10].

Co-generation is realized by car engines, a mass market in the proper sens of the word. The bio-fuels which are considered here for this purpose have currently a world market of 30 mio tonnes with considerable yearly growth rates; market leaders are Brazil and the U.S. The EU is also preparing for a major development of the bio-fuels market. A Directive from 2002 calls for a 5.75% share of them in all transport fuel which means a production in excess of 10 mio tonnes by 1010. The target is the transport sector, but as said before, we propose to use massively car engines in our strategy as well.

The batteries for short-term electricity storage must not be the standard lead-acid ones. Alternative ones, like Ni-metall hydrite or Li-polymer have well left the research Labs and entered mass production.

Important research is currently under way on a global scale to improve all the technologies of interest to us even further. The proposed systems will become more efficient and reliable, and cheaper. The conventional energy production, on the other hand, will become dearer as the fossil fuel inputs will follow the oil price increase: future trends are all in one direction, upwards - with the risk that another conflict in the regions where they are produced may trigger a world-wide bottleneck of supply. Electricity will also increase in cost because many of the old power plants in Europe, amortized as they were, will have to be taken out of production. Eurelectric, the power industry sees the need to install 520 GW of new capacity already by 2030 [9]!

5.3 Costs and policies

The core of the PV system cost, now and in future, is the cost of the PV module. The cost prospects of crystalline silicon and thin-film modules of the conventional types have been analysed several years ago, initiated by the author of this paper, by some of the best European expertise in the field [11], [12]. It was clearly demonstrated that eventually a production cost for the module – for the cells it would obviously have to be lower – of less than 1 Euro/Watt (peak) will be possible in mass production. It was a question of speculation if ultimately crystalline silicon or thin-film modules will become cheaper. It is also of little relevance to explore to every single cent what the exact cost may be. The uncertainties of longer-term developments make this absurd.

The kWh costs will be strongly influenced by the climate and the weather patterns at the site of installation. On conservative assumptions, the price could come down to 14 cents/kWh in central Europe and 11 cents in the south [13]. Here again it is too much speculation what the detailed price prospects are for the future. In Europe we want to be conservative in that respect despite the fact that the U.S. experts anticipate considerably lower price figures.

What counts in practice in the building sector is the question, how future prices of PV systems and the electric energy they produce compare with conventional electricity prices, or otherwise expressed, what autoproducers have to pay for amortizing their PV installation in comparison to the kWh price they pay to the provider on the grid. To analyse this further, we will go back to Germany for which some details are available [14]. There, the domestic end user pays now in 2005 typically 20 cents the kWh (it varies from region to region and between cities). It is interesting to note that only 20% of this amount goes to the power producer. More than 30% goes to the grid operators, 5% goes for measuring and the rest for taxes and the like – including sizable profits in all parts. Without wanting to go at this stage into the very complex price calculations of the power industry, it turns out that **PV will eventually become competitive in the power market on purely commercial grounds.**

This by itself justifies the financial and political promotion which is in place in Germany and some other European countries. The current promotional law based on fixed feed-in tariffs which are high enough to cover all costs, the EEG in Germany, is ideally suited to kickstart the large PV markets of the future. The built-in yearly cost degression of the PV price to be paid by the grid is the right approach to allow for the swing of prices down to commercial competitiveness while ensuring robust growth of the markets, the industry, businesses, and jobs. This efficient instrument should stay in place at least for the next 10 to 15 years, the time needed to exploit fully all cost-decrease potential. Later on, once autonomous power systems start to get more widespread in the building sector, more conventional financing schemes focusing on plant investment rather than the energy production may become more appropriate.

6 Conclusions

Climate experts around the world agree that it will not be good enough to stabilize GHG emissions by 2050 but that it is imperative to decrease them by 60% to 80% with respect to current levels. The re-insurance industry complains already about the increasing cost of the economic consequences of climatic degradations in parts of the world. As far as security of energy supply is concerned, it has moved now high on the political agenda even for those who do not want to believe in climate change.

But curiously enough, the “energy profession” does not take note. The World Energy Outlook of the International Energy Agency assumes under a ”reference scenario” that the global primary energy demand of coal, oil, and natural gas will increase a “healthy” 50% by 2030. Renewable electricity, apart from hydro, is given 6% at that time. The obvious contradiction between the geopolitical problems ahead and the “vision” of the energy profession may possibly be explained by the fact that for the established energy providers, trillions rather than billions of Euros of business are at stake.

The author remembers the headlines on the newspapers in the U.S. in 1973: “Lights out in Las Vegas”. The party was actually not yet over. But this time the signs on the wall eventually may announce blood and tears. PV and the renewables are not an ecologist’s dream; it is a viable option full of promise, a power for economic development and peace.

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Acknowledgments

The author thanks Dr.Hermann Scheer MP and Dr Peter Helm for interesting discussions. He thanks also ADEME, Paris, for its support.

About the author

Dr.W.Palz directed the EU Commission’s RE development programme from 1977 till 1997. He is currently co-operating with the EU Commission on PV deployment in Latin America to the benefit of the poor. He holds an Order of Merit of the Federal Republic of Germany and the European Awards on PV, Wind Power, and Biomass respectively.