ENERGY

Photovoltaics in urban energy systems in Europe: current policies and the need for policy change

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The role of PV in European electricity systems is described focusing on urban applications. In this context, challenges associated with rapid PV expansion are delineated and PV support mechanisms are discussed.

Cities and urban areas are the dominant electricity load centers, but they rarely produce their electricity within their boundaries. More often, the electric energy generation takes place in large, centralized power plants sited outside of the city perimeter.

Photovoltaics (PV) as a rather novel, carbon-free, decentralized electricity generation technology has a considerable potential to increase a city's own electricity production by bringing electricity production -- and notably also value creation -- closer to the electricity consumption and thus also limiting the need for the controversial expansion of interregional transport infrastructure. Yet, PV is not without critics on grounds of the technology's still higher cost compared to conventional generation technologies and grid integration issues.

This article describes PV's role today in European electricity systems with a focus on its urban applications. In a case study for an urban electric utility, the potential of PV as well as its challenges associated with rapid PV expansion are delineated. Following the description of technical approaches to addressing these challenges, it discusses the PV support mechanisms at the disposal of municipalities, and it points out the importance of national energy policy as an enabler for effective sustainability-oriented local level action.

Relevance of photovoltaic for urban energy systems

PV looks back at a remarkable success story in Europe. In terms of installed PV capacity, Europe is the world's distant leader. At the end of 2011, European grid-connected PV capacity made up more than two-thirds of the world's total. On the European level, Germany and Italy stand out as the PV frontrunners with PV capacities of 24.8GWp and 12.5GWp, respectively. For illustration, Germany's PV peak capacity equals the generation capacity of 25 medium-sized nuclear power plants; its capacity per capita in excess of 300Wp translates into roughly one modern PV panel per inhabitant.

Disaggregated statistics on PV's rural-urban distribution are not available, but the share of roof-top to total capacity seems to be a reasonable first approximation. According to statistics of the German Solar Industry Association, more than 80% of Germany's total is roof-mounted. Similarly, roof-top systems are by far the dominant system design in other densely populated countries (i.e., Belgium, Italy, the Netherlands , Switzerland, UK). Only in a few European countries such as Greece and Spain, where ground mounted PV system face little land use competition, this ratio is below 20% (EPIA, 2012). It must be noted, however, that the ratio of roof-top installations overestimates the urban PV penetration to some degree as it also includes sub-urban and even rural areas.

Irrespective of the exact penetration, the magnitude of the numbers shows that PV has outgrown its technological niche and evolved into a proven and reliable generation technology supported by a large and professional supply and service industry. For cities, PV is of particular interest as it is one of the few generation technologies that is capable of integrating harmoniously in the city structure without causing public resistance. In fact, PV enjoys a particularly good reputation in the public opinion as recent surveys found. In the future, the technology is very likely to capture an increasing share of total electricity generation. PV prices have steadily fallen in the past—50% since 2008 alone (BSW, 2012)—and the price erosion is widely expected to continue as the relatively young technology is bound to benefit from the very active research in the area as well as learning and economies of scale in PV cell and module manufacturing.

Using PV as integral elements of building envelopes,

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Building-Integrated Photovoltaic (BiPV) has emerged as an important driver of urban PV growth. Three drivers are at the core of this development. Firstly, technological advances multiply the potential applications of PV. (Semi-)transparent and flexible PV cells have recently been brought to market. Secondly, architects as well as constructors are becoming increasingly familiar with PV. The technology that was formerly labeled as a technology for environmental enthusiasts is becoming increasingly accepted or even considered state-of-the-art. Thirdly, the unprecedented PV prices are more and more rendering BiPV the least-cost option or, in other words, the use of PV becomes economically attractive. Interesting examples of BiPV are the Sun Ship in Freiburg im Breisgau, Germany (http://plusenergiehaus.de), and the Amplicación Corte Inglés Castellana office tower in Madrid, Spain.

Generally speaking, the integration of PV into urban energy systems is not without merit as it potentially entails technical, environmental, economic, as well as political advantages such as diversification of the electricity mix, emission abatement, reduction in import dependence and in transmission grid expansion requirements, and also lower peak load demands. In the recent past, however, the technical challenges associated with the integration of a high share of PV have surfaced, too. As a case in point, the German government sees the urgent need for decelerating PV growth and improving its grid integration following the rapid growth in the past. Said grid integration challenges are linked to PV's 'intermittency' and 'variability'. Intermittency describes the daily and seasonal changes in the actual electric energy production due to the varying availability of solar radiation. Variability refers to the practically unpredictable, minute-to-minute volatility of PV electric energy production due to external, uncontrollable meteorological factors (such as cloud cover or high fog). Both characteristics—likewise properties of wind energy and other renewables—and their impact on grid stability are described in the following case study.

badenovaNETZ case study

badenovaNETZ is the distribution grid operator in the city of Freiburg im Breisgau, Germany, and the adjacent region in Germany's south-west. Freiburg, blessed with some of the best solar conditions in Germany, has one of the highest PV penetrations per capita among Germany's large cities. Thus, the situation in the badenovaNETZ grid foreshadows what other city grids might be facing in the near- and mid-term future and provide the rationale for this case study.

Installed PV capacity at the end of 2011 stood at approximately 30MWp from approximately 2,400 plants. Reflecting the large number of small roof-top installations, the average solar array size is currently of the order of 12kWp. The largest plant connected to the network is a ground-mounted 2.5MWp installation on a former landfill located between two of the city's industrial zones. Total PV electricity in 2011 was approximately 23million kWh or 4.9% of total electric energy consumption.

Figure 1 shows the actual PV feed-in for two selected, non-representative weeks on the badenovaNETZ grid: a sunny summer week and a winter week with low PV production.

The bell curve-shaped production profiles in both diagrams of figure 1 illustrate daily intermittency. The dramatic difference in PV feed-in between summer and winter make clear the magnitude of PV's seasonal intermittency. In summer, PV provided a considerable 4.7% of total electricity consumption. In the winter week, where production amounted to a mere 3.5% of the summer week, this share dropped to a 0.2% of total consumption in the same week. The rapid variations in feed-in on September 26 and on most of the winter days illustrate PV's variability.

In Figure 2, the actual grid load of badenovaNETZ is superimposed on the summer PV production curve. With peak production coinciding with maximum load on the grid, PV electricity helps cover peak demands. What is advantageous today can become a disadvantage tomorrow when PV growth continues unabated without accompanying measures. In a not too distant future, the electricity system (production and consumption side) may be incapable of providing sufficient balancing capacities whenever PV production rises or falls with a blackout as a worst case consequence. Concretely, the dotted PV feed-in curve in figure 2 simulates the badenovaNETZ with 5-times today's PV capacity. At recent growth rates, such a scenario may only be a few

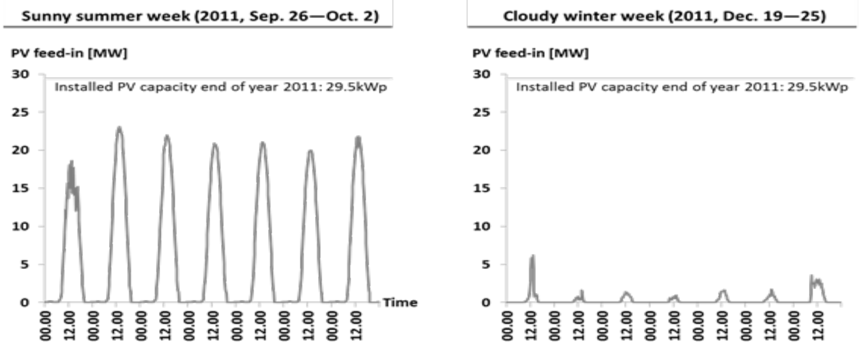

Figure 1 | PV feed-in on the badenovaNETZ grid in two selected weeks in 2011

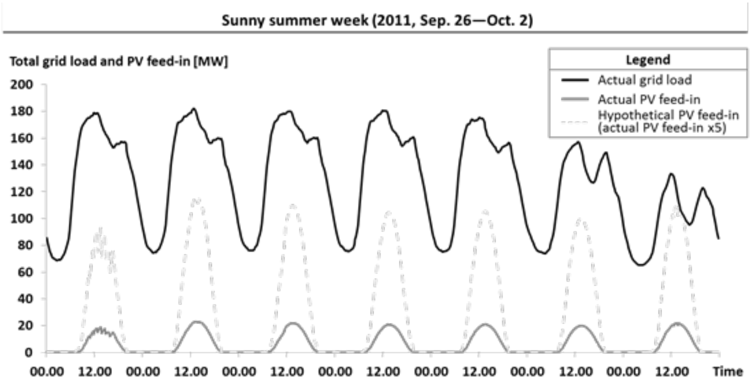

Figure 2 | Total grid load and PV feed-in on the badenovaNETZ grid between 2011, Sep. 26-Oct. 2

years away. Total PV capacity of some 150MWp on the badenovaNETZ could be reached before 2020 at 25% p.a.

Technical options for grid integration

The integration of large PV capacities is technically feasible and comes with the numerous advantages mentioned earlier if managed proactively and if relatively higher costs are collectively accepted. Technical solutions exist and research and development in this area is very active.

The obvious approach to managing grid stability in a PV-heavy grid is the curtailment of PV feed-in cases of surpluses—essentially what a system operator would do with a conventional plant in such a situation. Being the obvious approach, it is also the least desired one as it is tantamount to the waste of carbon-free electricity. While the curtailment may at times be indispensable for grid stability, there are other, less controversial ways to improve the grid friendliness of PV too. A broadening of PV's production profile through a diversification in plant orientations as well as the installation of PV capacity close to load centers have a considerable potential to mitigate the technical challenges.

Nevertheless, measures improving grid friendliness of PV alone will not suffice to guarantee grid stability. There is little disagreement in the literature that high penetrations of PV and other intermittent renewable energies demand a more flexible electricity system than the current one. Broadly speaking, operational flexibility of the grid rests on three pillars:

- flexible generation;
- electricity storages;
- load management.

For the urban energy system, load management, which refers to the active, directed adjustment of loads in response to variations in electricity production, and electricity storages are particularly relevant. Today, load management takes place primarily in industry. Large industrial electricity consumers shift electricity-intensive processes to low demand periods in order to benefit from lower electricity prices. Load management potential likewise exists in the commercial and residential sector, notably for thermal applications such as refrigerators, heaters, and air conditions, without or at limited loss of comfort, but this potential is only exploited in small pilot projects due to market, technical, and institutional hurdles at present.

The storage of excess electricity during phases of surplus and for discharge at times of shortfalls is the other promising approach. Intuitive in theory and thus so appealing, electricity storage is, however, complicated in practice. As a general rule, the current storage technologies are characterized by at least one of the following disadvantages: low energy density, high investment cost, low reliability, or high conversion losses. Pumped water, the world's dominant bulk energy storage technology, requires huge reservoirs to store significant quantities of energy due to its 99.998% inferior energy density compared to gasoline. Chemical storages (i.e., hydrogen or methane) do away with this handicap, but suffer from roundtrip efficiencies of some 30% (Specht et al., 2010). In the recent past, small lead-based batteries were brought to the market and promoted as a solution to the grid integration problem. Yet, recent research has shown that decentralized battery systems designed to maximize the plant owners' own use have a tendency to make PV grid more difficult (Sauer et al., 2011). If any, grid benefits originate from decentralized storages only if the grid operator has control over them. Medium- and large-size storages connected to the medium- and high-voltage level have the highest potential to increase network flexibility.

Policy support today and the need for change

Traditionally, energy policy is a national policy domain. As a case in point, the policy instruments that have been driving the growth of PV in the past—feed-in tariffs, tax incentives, investment subsidies and grants as well as development loans—have been programs initiated, financed, and managed by the federal or central government (REN21, 2011). Hence, municipal decision and policy makers can hardly stimulate the growth of PV and other renewables without or even against the national legislator. Yet, on condition that national policies are in place that regulate grid access of renewables and their feed-in, municipalities can draw on a wide array of instruments to promote PV and other renewables ranging from regulatory measures to financial incentives as well as voluntary action and information. Acknowledging their responsibility for energy efficiency and the promotion of renewable energies, some 4,000 European local and regional authorities to date have signed the Covenant of Mayors and therewith declared their commitment to working towards exceeding the EU emission reduction target of 20% (http://eumayors.eu).

In the past, renewable energy targets have been a very popular instrument among European cities. Although these targets fall short of being legally binding, they provide a framework for regulatory activity and a guideline for action for the municipal administration itself. As a consequence of a stated renewable target, building codes may be amended as to include obligations on the use of renewables. In Barcelona, for instance, permitting procedures for buildings beyond certain size thresholds command the use of either PV or solar thermal installations. The integration of renewable energy aspects into urban planning and zoning represents another avenue on the part of city managers to actively managing—the management need not be limited to the promotion of renewables-- the future deployment of PV within the city boundaries. Targets for the own-use of energy produced by renewables, along with demonstration projects, are instruments that allow cities to lead by example.

Investment grants are a common financial incentive for renewable investments. Freiburg's utility badenova supports PV investors with a one-time subsidy of up to €900. A development loan program, potentially managed by publicly-owned municipal or regional savings banks, is another very powerful instrument to induce PV investment.

Municipal manager can provide an important stimulus to PV, but the broader renewables-enabling regulatory framework is set by the national policy makers. In the pioneering countries Germany and Italy, where PV penetrations increasingly call for complementary measures, policy makers must address these challenges to unlock potential for further PV growth. As this discussion would go beyond the scope of this contribution, only a few aspects related to broader policy enablers of PV are briefly mentioned. Going forward, the primary objective of PV-enabling policy activity should be geared towards increasing grid friendliness of PV generation. Location- and orientation-differentiating feed-in tariffs help broaden PVs typical noon-centered production profile and prevent undesired regional concentration. Invariability bonuses such as for PV-system integrated storages could aim at increasing the operational flexibility of PV. The secondary policy objective should address the flexibility of the electricity system as a complementary measure to increase the electricity system's capacity to accommodate large amounts of intermittent renewables. There is increasing consent that the existing electricity market structures and the static legacy approach to electricity sector regulation (i.e., unbundling) are ill-suited to trigger investments in the required flexible generation and storage infrastructure. On the demand side, policy support for the setting of uniform standards as a precondition for the development of smart grids is in high demand.

Conclusion

Photovoltaic electricity generation has come of age. A large and highly competitive photovoltaic industry has developed and several multi GW-markets have emerged in Europe alone. In pioneering countries, PV has captured a considerable share in the electricity mixes within only a few years thanks to strong political support.

PV integrates particularly well into urban energy systems due to its modularity, emission-free electricity generation and the practical absence of competition for the use of suitable surfaces. Public resistance against PV is limited due to the noninvasive impact on urban landscapes. Going forward, PV is likely to get a further boost as architects and contractors in cooperation with PV manufactures commence to capture the full technical and economic potential of BiPV.

Municipal policy makers have multiple means to stimulate the deployment of PV and have used them in the past. Specifically, renewable targets, building codes requiring renewables, demonstration plants, and financial incentives are the instrument most in use. For municipal regulatory and policy action to be effective, however, national energy policies regulating PV's grid access and feed-in are a precondition.

In light of the problems associated with an uncontrolled PV growth, national energy policy makers are called upon to adjust the existing policies stimulating PV development. The prior focus on a maximum PV electric energy generation must be complemented with a quality notion. Furthermore, complementary policy measures to enable investments in infrastructure increasing operational flexibility must be actively pursued.

Granted, the number of issues and their complexity is significant, but they are required sooner rather than later if European national and urban policy makers want to deliver on their renewable targets and their climate change mitigation commitments. ★

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