ANCRE

Alliance Nationale de Coordination de la Recherche pour l'Énergie

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Decarbonization Wedges Exercise

Solar Photovoltaics

1. State of the art and current development in different world regions

Photovoltaic energy involves using solar irradiation to produce electricity. Within each technological family, more and more technologies are becoming available. On the one hand, it makes it difficult to predict which of these technologies —if any— will prevail; on the other hand, since there are a lot of technologies, the decreasing trend is all the more robust and predictable.

Technology 1: Conventional silicon (crystalline silicon)
Over the last three decades the crystalline silicon technology always had a world market share of 80 to 90%[1], although the market increase used to be a thousand times weaker as it is now. Improvements mainly come from cheaper materials, higher efficiencies and higher-throughput processes.

Technology 2: Advanced crystalline silicon
This technology uses higher quality material and more advanced processes. When used in a limited space —on a building, for example—, this technology clearly provides the highest amount of energy, which results in a real premium.

Technology 3: Thin films
This technology has a smaller relative market share —around 10% of the global PV module sales. Their module efficiency is slightly lower. However electricity costs are similar in locations where space is not an issue. In some cases, thin films technology can bring some advantages like aesthetics and flexibility —modules using thin film technology are also lighter.

Technology 4: Concentrated PV
Concentrated PV has a very low market share— i.e. below 1% of the global market. There are however big prospects due to the latest advances at the cell level which have led to a 30% current commercial module efficiency, with a R&D record at 36%. Good efficiency can be achieved through the installation of a sun tracking system, which leads to higher production costs.

Many other technologies could be mentioned. However their market penetration ratio is below 1‰. These technologies include organic PV, dyed-sensitized solar cells, kesterites, perovskites, etc. For the future, mixtures of some of these technologies, either separately or with silicon technologies can be also considered to sustain improvement along the learning curve.

2. Maturity level and technological perspectives

Maturity of elementary technologies associated with PV

Methodological information:

The maturity level is the TRL, reduced to 5 levels with market deployment enclosed in the higher TRL classes; maturity level scaling: 0 = none; 1 = fundamental research; 2 = R&D; 3 = demonstrator; 4 = low deployment; 5 = large deployment.

	2015	2020	2030	2040	2050
Conventional Silicon	5	5	5	5	5
Advanced Silicon	3	4	5	5	5
Thin Films	2	3	4	5	5
Concentrated PV	3	3	4	5	5

[1] Source: IEA 2014

Potential development of technologies related to PV

Methodological information:

Potential development is measured as the percentage of the technology's contribution to environmental protection. This means evaluating, in terms of carbon emissions and of carbon emissions reduction, to what extent this new technology can contribute to limiting temperature increase to 2°C above pre-industrial level according to the time horizon considered in this study. Potential development scaling: 0 = not significant; 1 = significant (i.e. more than 1% of global emissions reduction) in some countries; 2 = significant on the global scale; 3 = very significant on the global scale (i.e. up to 3% of global emissions reduction); 4 = major technology vs. climate change (i.e. more than 3% of global emissions reduction).

All technologies are mature and will penetrate the market by 2020.

	2020	2030	2040	2050
Potential development	4	4	4	4

Photovoltaics currently account for a large part of new energy installations and this will still be the case, even after 2050.

The number of countries with an annual photovoltaic capacity above 1 GW is dramatically increasing, which makes the growth of the global market very robust, as it is less and less based on incentives policies of a few motivated countries and more and more related to economics.

3. Technological, economic and social bottlenecks

Methodological information:

The following table ranks the bottlenecks according to their impact on the development of the technology. A bottleneck ranking at 6 on the scale will hinder or stall the deployment of the technology compared with bottlenecks ranking at 1; conversely, a bottleneck ranking at 1 will hinder the deployment of the technology much less than bottlenecks ranking at 6. Note that the ranking is relative, meaning that a bottleneck ranking at 6 is not necessarily hard to remove; conversely, a bottleneck ranking at 1 is not necessarily easy to remove. Technologies rank according to: research, finance, regulations, resources & environment, security and acceptability. The table also contains keywords associated with each bottleneck.

Technology		Research & technological bottlenecks	Economy and financial bottlenecks (investment, risks)	Regulation & institutional environment	Resources & environmental impacts (including scarcity of raw materials, water, land, climate)	Safety & security (impacts on health, people and security assets)	Socio-technical feasibility
All technologies	Rank	4	5	6	3	2	1
	Key-words	Ineffective allocation of funds: only the public sector is involved in R&D	Low profitability	Access to grid should be created and European policies should support the industry	Rare metals	Toxic metals	

All photovoltaic technologies are facing the same bottlenecks. This means that:

1. There are no bottlenecks regarding environmental impacts, wastes, safety of supply, safety and security, insurance issues, transfer of costs to next generations, health issues, social acceptance, etc., whatever the regions;
   However another issue may be the scarcity of raw materials (i.e. tellurium, indium) and the toxicity of others (Cd) for two or three technologies, which therefore are working on alternatives, like the indium-free CZTS;

2. The three critical issues are:
   - Regulations —grid access, associated business models, soft costs, support towards a European industry;
   - Financing, with access to low WACC;
   - A more balanced distribution in the energy research funding.

Besides the PV industries benefitting from large market shares can support some R&D activities —mainly incremental innovations—, whereas technologies involving disruptive processes and technologies can have access only to public funding.

Both the social acceptance and the financial bankability are very much in favor of the development of PV technology. In most countries populations usually think of PV as the first source of electricity to be developed.

4. Potential radical and incremental innovations

Methodological information:

The following table lists the nature of innovations needed to overcome the bottlenecks mentioned earlier. There are two types of innovations: I stands for 'incremental innovation' (i.e. improving existing products and processes) and R stands for 'radical innovation' (i.e. developing new products and processes).

Technology		**Research & technological innovations**	**Economy and financial bottlenecks** (investment, risks)	**Regulation & institutional environment**	**Resources & environmental impacts** (including scarcity of raw materials, water, land, climate)	**Safety & security** (impacts on health, people and security assets)	**Socio-technical feasibility**
All technologies	I or R	R	I	R	I	I	I
	Key-words	New materials		Administrative barriers, network, carbon tax			

All the main technologies have been known for more than 30 years so far.

Both radical and incremental innovations are required —mainly a whole set of incremental innovations, and sometimes radical innovations related to the use of new materials or new high-throughput processing steps. To make this happen, it is crucial to strengthen research, development and demonstration efforts to further reduce costs and to organize the manufacturing scale-up.

However the main radical changes expected for the PV development are related to regulations: e.g. removing administrative barriers to the connection of distributed power generation systems to the distribution grid, evolving toward more equitable market conditions by eliminating subsidies to fossil sources, integrating of external costs — i.e. carbon tax— and benefits related to renewable resources.

New business models, new regulations regarding building codes and grid codes have to be implemented. The speed and magnitude of this implementation will largely impact the diffusion of PV technology but it clearly depends on the ability of governments to carry out the energy transition.