How the European Commission Policy Supports Research and Development in Photovoltaics

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Abstract

The paper presents an outlook of the European Commission’s policy in supporting research and development (R&D) in photovoltaics (PV) and its mainstream adoption. It analyses the key elements of the EC policy aimed at securing for the European Union leading position in a global competition in PV, including the Strategic Energy Technology Plan, the H2020 Framework Programme and the Energy Union strategy. The paper also analyses the key areas of PV technologies development in Europe as stimulated by R&D funding, the magnitude of investment and particular research topics supported by the EC (with focus on one of the 12 Key Enabling Technologies for the European Union identified as perovskites), as well as the general progress of European PV technology in its international context. Finally the paper addresses the renewables and in particular the role of PV in the European Union COVID-19 pandemic recovery strategy. The paper also discusses the PV R&D potential versus other, traditionally dominating renewable energy sources, such as wind power and hydro power.

Key words: European Union, European Commission, policy, PV, photovoltaics, research and development, renewables

1. Introduction

In 2020 photovoltaic energy may have finally become the cheapest source of the electrical power in developed countries at price of circa 0,014 Euro/kWh (Qatar General Electricity & Water Corporation, 2020 – price agreements for the Al-Kharsaah Solar PV Power Plant), with the solar cells panel prices dropping by one order throughout just the last decade.

This new domination of PV as the most economically viable electrical energy source opens new competition grounds for accelerating transition to sustainable clean energy. It does not mean however that this transition will happen overnight. It is a process of significant costs and efforts that will be however further supported by the EU policy. It is assessed in the European Commission’s Strategic Energy Technology (SET) Plan that the PV competitiveness opens a path to a global transition to sustainable and clean energy which is critical in mitigating global warming. The climate situation is generally perceived very serious by numerous studies and the EU policy. The EU emissions budget for CO_2, in order to meet the 1.5 'C degree limit of temperature rise policy target, would be used up in 2028 if these emissions (mainly associated with energy production and transport) were to remain on the current levels. Utilization of PV as a main source of electrical energy (along with simultaneously developed storage systems and smart grid integrations) is expected to increasingly support the transition process along with the COP21 goals and the EC policy has an important role to facilitate this on the level of R&D.

The PV energy experienced exponential growth over the years, with massive 50% per year in the last 10 years (recently dropping however to 30%) – as reported by the IEA (2020). The installed capacity exceeded 132 GW in the EU alone at the end of 2019 (cf. Jaeger-Waldau 2019). and dynamically growths further on (steadily nearing to a double digit % in the EU electricity demand growing from the 5% level as reported back in 2017). Germany was leading this growth worldwide, followed by China, Japan, Italy and the US (Fraunhofer ISE 2020, World Energy Council 2020).

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Europe has also became a strong player in PV research and technology development worldwide. In line with deployment on a large scale, the strong R&D position of the EU and price competition from China resulted in PV module prices dropping by about 80% already between 2009 and 2015 (Jaeger-Waldau 2016).

The European SET Plan intends to contribute to further cost reductions and to relaunch PV cell and module manufacturing in the EU. The Energy Union policy set out on basis of the above mentioned European Commission communicated standpoints in particular address the two following goals: 1) putting energy efficiency first and 2) achieving global leadership in renewable energies. The EC has estimated that in order to reach the EU's 2030 climate and energy targets, about €379 billion investments are needed annually over the 2020-2030 period (with €27 billion devoted to public and private research annually) with significant shares needed to be targeted at further development of solar energy and photovoltaics.

The paper studies the current European policy towards PV R&D as defined in the relevant scope of the H2020 Work Programme, the European SET Plan, the Energy Union implementation and the new impetus of the European Green Deal from the newly appointed European Commission.

2. Background of R&D in photovoltaics – the dominating potential of PV

Both in the EU and globally photovoltaics is currently the third renewable energy source in terms of installed capacity (after hydro and wind power). But how the PV potential compares to the two latter renewables?

The potential of the photovoltaics surpasses the potential of hydro and wind power. To visualize the differences, one should point accordingly to calculations done in (Berners-Lee, 2019), that in order to cover the whole current United Kingdom’s energy demand with wind power – it would be necessary to cover whole its land surface with wind turbines (and it would still provide just a little over 90% of the required power output). On the other hand to cover the whole current global energy demand with PV it would be required to cover 367 x 367 km^2 area with solar panels (this is only 3% of the EU surface, or just 1.4% of the Sahara desert surface). The global energy demand is ca. 165000 TWh and the UK demand is just 2200 TWh – 1.2%. To cover UK energy demand with PV one would need just below 0.7% of its surface vs. circa 110% of its surface covered by wind turbines. To cover the EU energy use (ca. 16000 TWh) with PV just 0.3% of its area is needed. Here we discuss these calculations under the assumption of using mass-produced, cheap and stable solar cells at only 16% efficiency and an averaged Sun irradiation, so actually in Sahara desert, one of the world’s top areas as per the intensity of insolation, it would be even less than 1.4% of its surface.

Cheap and mass-produced 16% efficiency solar panels covering just 0.1% of the Earth land surface can meet the total energy demand today (or as mentioned well below 1.4% of the Sahara desert area). Wind power is no match for this potential (as e.g. to meet the UK’s energy demand 110% of its territory would have to be densely covered by wind turbines – solar panels would require ca. 0.7% area – cf. Berners-Lee 2019, Smill 2017, Miller et al. 2011, Peixoto and Oort 1992). Similar situation is with the hydro power. Physical energy estimations in detail presented by Smill (2017) and also discussed by Berners-Lee (2019) prove that if we harness potential and kinetic energy of every droplet of water pulled by gravity from wherever it lands (before it reaches its minimum energy state in the seas or oceans) or in other words, if we would extract all energy from every stream of water moving on Earth (including oceanic waves energy) it would just about meet the current total energy demand on a global scale. Although such an endeavor is in itself unrealistic and impossible to be implemented technically, it would still supply energy at many orders below the above estimated potential of the PV.

PV thus leaves behind the limited wind & hydro power in terms of energy potential and is the best alternative to solve energy problem versus climate change, at least until there is nuclear fusion technology breakthrough.

For the time being however, the proper argument for the policy makers working on the clean energy transition, renewables and mitigating climate change strategies is not by how many times the PV is better energy source than wind and hydro power (and even thermal solar power, especially when it comes to the electricity generation), but rather by how many orders it is better.

PV is also very promising in terms of research and development. The current mainstream PV technologies (mainly Silicon wafers) being at ca. 16% efficiencies are being in a quite fast pace replaced by the so called emerging third-generation solar cells (also cheap but with many advantages, such as lowered sturdiness, flatness of thin-film architectures, elasticity, semi-transparency, etc.). The advanced tandem configurations of new solar cell devices (multi-junction or multi-layer setups) reach almost 50% of the efficiency.

The main aspect of the pronounced R&D efforts in PV is of course reduced to the end price per Watt of power generated, and the technological results as well as objective potential of extracting energy directly from sunlight in a photoelectric effect begin to dominate the spectrum of renewable energy technologies.

3. Current directions in the PV R&D

What are the current directions in photovoltaics research and development? One of the most famous short summarizing-answer to this question is to refer to the National Renewable Energy Laboratory Best Research-Cell Efficiencies graph. The 2020 NREL graph has been placed accordingly with the credited reprinting terms in the Fig.1. (NREL, 2020). It shows how the efficiencies of different PV technologies develop across the recent half-century.

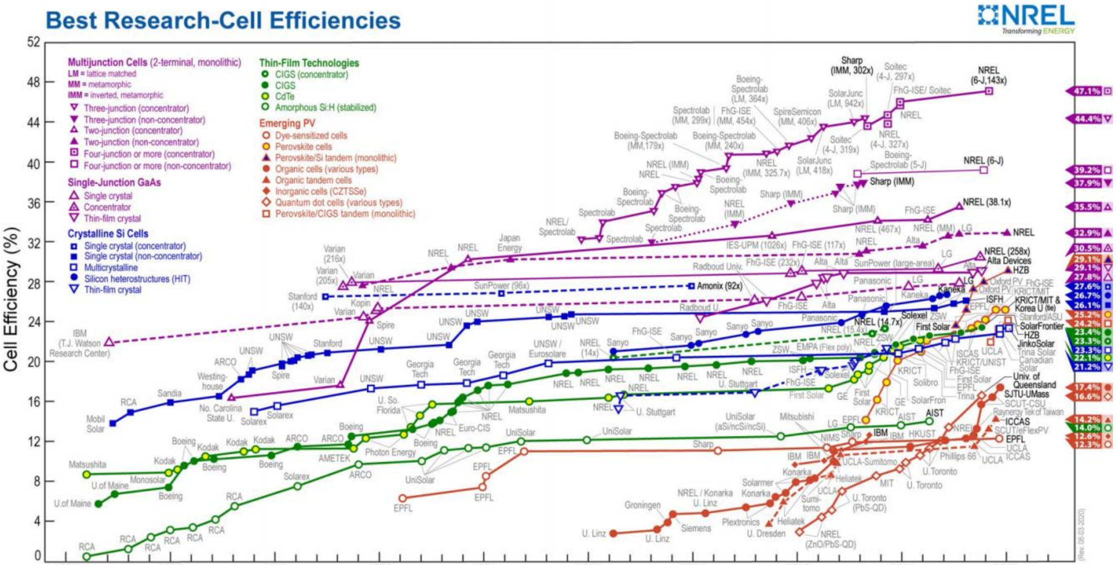

Fig. 1. Summary of the global R&D directions and achievements in PV efficiencies.
Source: National Renewable Energy Laboratory, US Department of Energy, 2020

The colors represent division into main categories of the researched solar cells. The most efficient but also most sophisticated and expensive technologies are the multi-junction (multi-layered) solar cells colored in magenta. These devices combine various other solar cells technologies to stack them up together in the best configuration possible. The most traditional and holding a dominating share (95% - Fraunhofer ISE, 2020) in market and production output are crystalline silicon cells, represented as blue and generally referred to as the first generation solar cells. The green color is reserved for the traditional thin-film cell technologies based on the 3 dominating materials, the copper indium gallium selenide (CIGS) cells, the cadmium telluride cells and the amorphous silicon cells. These technologies are already widely applied in PV power plants and referred to as the second generation solar cells, showing a steady but improving performance over the years similar in magnitude to the first SC generation. Finally the orange color represents the new trends in PV R&D, i.e. so called emerging solar cells technologies, including dye, organic, quantum-dots and perovskite devices. These new material and architecture devices (most commonly in elastic thin-films configurations) are considered the third generation solar cells and their physical operation goes beyond the standard p-n junction model, thus holding a potential to overcome the theoretical Shockley-Queisser limit for the efficiency of a single-junction solar cell. The main advantage of the not-yet commercialized emerging PV technologies are the promise to bring high-efficiency at a low cost of production combined with thin-films advantages.

The key conclusions that one can draw from the NREL graph, is that the upper half of the graph, i.e. values above 30% efficiency (magenta color) are solely reserved for the multi-junction solar cells. This follows directly from the physical Shockley-Queisser limit (cf. Shockley and Queisser 1961), which refers to the calculated maximal theoretical efficiency of a solar cell based on a single semiconductor p-n junction (practically a single solar cell device layer) to employ a photoelectric effect with losses limited only to the radiative recombination. The value of the SQ limit has been calculated at 33.7% efficiency under the normal sunlight conditions (unconcentrated light, perpendicular incidence on the solar cell surface), assuming typical sunlight conditions and the most optimal to the Earth surface sunlight energy spectrum material semiconductor bandgap of 1.34 eV (cf. Rühle 2016 – conditioned by the light absorption in the atmosphere and corresponding to circa 925 nm near-infrared photon wavelength). The semiconductor bandgap refers to the semiconductor material potential energy barrier between the conductive and valence bands, that needs to be aligned to the energy of the incident photon, which when absorbed by the electron from the valence band, gives it the exact energy needed to overcome the potential barrier and conduct electricity in the conductive band – the basis of the photoelectric effect which is generating photocurrent as explained by Einstein in 1905.

From the SQ limit it follows that a single-junction SC theoretical energy efficiency is limited at circa 33%, meaning that from an averaged sunlight energy density of 1000 W/m^2, such cells can maximally harvest about 330 W/m^2. This is where multi-layered (so called multi-junction or tandem architectures) have their say. From the NREL graph one can see the most efficient solar cells researched up to this date are currently the devices incorporating as many as six junctions (layers), horizontally stacked one on the other to reach the 2020 record of 47,1% of the efficiency. The theoretical limit calculated for a model of an infinitely layered multi-junction solar cell is circa 86.8% under the assumption of the concentrated sunlight harvesting design using e.g. optical lensing (i.e. a concentrated photovoltaic system, CPV).

As the multi-junction cells with various materials and architectures stacked one on the other with up to 6 layers are complicated devices their main drawback is cost of the production (increasing unitary cost of energy generated), shortly followed by robustness and durability. These devices are thus less practical for mass applications such as large areas coverings (e.g. in architecture), which is taken into account in R&D planning.

Thus rather more important from the current absolute position of the researched PV technology efficiency on the NREL graph is the recent growth dynamics (i.e. how steeply is the curve going up). On the graph on Fig.1. we can see that the major emerging low-cost PV technology is now the perovskite solar cells (indicated with orange-yellow circles) undergoing spectacular growth from just few % to over 25% efficiency in the last few years. These are thin-film elastic solar cells that caught up in efficiencies with the PV dominating crystalline Si wafers and are easier and cheaper to produce (in the ink-jet printing or roll-to-roll processes well suited for the mass-output production and versatile applications). In more details: the efficiency of these cells has been lifted from 2% (2006) and 3.8% (2009) to 25.3% (2019) and circa 30% (in tandem) and its further increase (up to 40% relative increase as proven in trial experiments) due to metallization incorporating plasmonic-enhancement (cf. Jacak 2020) is highly impressive and carries significant market potential for mainstream proliferation of PV. This is also the PV technology in which the European Union has a very strong research position and the PV technology that holds an important priority context as the KET for the EU.

4. EU Key Enabling Technologies context of the PV R&D

At the end of 2017 the European Union has concluded a study on Key Enabling Technologies for achieving technological global supremacy for the EU (Dervojeda et al. 2017). Upon the relevant studies a total of only 12 promising KETs were identified among all technologies as the ones that hold a potential for the EU to assure through further development that the EU industry in those KETs respective areas will stay ahead of international competition. In energy context the perovskite solar cell technology was defined as one of the KETs for the EU.

Perovskite solar cell is considered the EU Key Enabling Technology mainly due to its excellent efficiency/cost ratio and other key properties such as semi-transparency and elasticity allowing bending and forming these PV devices into different shapes/surfaces coverings, as well as due to the EU securing a leading position in this technology. As buildings are estimated to account for over 40% of the energy demand in the EU, building-integrated solar cells are the primary application for PV. Perovskite in contrast to sturdy Si panels offer simple whole-surface coverings techniques including aspects such as architectural freedom.

What are the main advantages of the thin-film perovskite solar cells? This elastic ultra-thin-film PV technology easily and cheaply ink-jet or screen printed in simple roll-to-roll processes or even sprayed onto large surfaces similarly like ordinary paints that when activated with chemically induced crystallization process make thin-film layers (thickness below 1 μm). These cells are therefore very well suited to mass-output market uptake and vast applications (such as energy smart buildings elevations coverings of variety of geometries, semitransparent or smart windows, roofs coverings, outdoor furniture, vehicles or even clothing external surfaces that may produce enough power to charge a phone). As the efficiencies rose rapidly from just 2% in 2006 to 25.3% in 2019 and up to 30% in tandem, currently these top values come at the cost of the stability and durability problems at higher efficiencies (the mass produced perovskite solar cells are currently stable at ca. 15%-16% efficiency). But the research and investment is dynamic.

The perovskite solar cells enable also advanced applications. E.g. in 2019 NASA announced plans (Herrick 2019) of launching trials with ultra-thin perovskite PV modules transported to orbit or even to the Moon or Mars in liquid form enabling ink-jet printing on-site in space of thin-film modules replacing conventional sturdy panels. Simultaneously new concepts to improve the technology are researched, including the promising metallic nano-modifications for the plasmonic-mediated PV efficiency gain, proven achievable in a relative value of 40% (Laska et al. 2020).

5. How the EU supports R&D in PV

Similar as with all renewable energy sources R&D funding in general, it is the industry which provides most of the research investment in the PV sector in Europe (with estimated 2B Euro in 2020, followed by the public funding from the EU countries, jointly contributing already over 1B Euro).

The joint magnitude of the public support of the European Union Member States towards PV R&D and its annual growth rate are thus significant (at amount of about half of the private investment level).

The European Commission itself in 2019 granted funding for the PV R&D sourced from the EU budget which amounted to over 500M Euro from below 100M Euro back in 2015.

The key overlapping vehicles for this support in the European Union are the:

- Horizon 2020 (H2020) R&D Framework Programme
- Strategic Energy Technology Plan (SET Plan)
- Energy Union Strategy
- European Green Deal

The EU funding of various projects in renewable energy sector is mainly implemented through:

- Cohesion Fund
- Connecting Europe Facility
- Horizon 2020 and Horizon Europe
- European Regional Development Fund
- European Investment Bank and the European Fund for Strategic Investments
- The Just Transition Mechanism
- Financing Energy Efficiency
- The Innovation Fund
- European Energy Programme for Recovery

For more details refer to publication on the European Commission 2020 – Funding Possibilities in the Energy Sector (https://ec.europa.eu/energy/funding-and-contracts/eu-funding-possibilities-in-the-energy-sector_en).
Below an outlook through the main initiatives for the PV R&D support in the EU is given:

5.1. Horizon 2020 and Horizon Europe

The Horizon 2020 is the 2014-2020 financial perspective EU R&D 8th framework program (FP8). The program enables grants for research and innovation projects through open & competitive calls for proposals independently evaluated by relevant experts. H2020 implements the European Environmental Research and Innovation Policy which prioritizes R&D in sustainable energy, including PV.

The H2020 has 3 pillars: Excellent Science (ES), Industrial Leadership (IL), Societal Challenges (SC). PV calls are programmed under the SC pillar in Secure, Clean and Efficient Energy area. Out of H2020 €77 billion budget, €5.9 billion is allocated to non-nuclear energy R&D. PV calls are in Research and Innovation Actions (RIA). Alternatively the advanced scientific proposal on PV R&D may qualify for funding under ES pillar in FET calls (Future and Emerging Technologies).

The H2020 is also supplemented by other funds (e.g. HERMES regional development fund) in transnational member-state programmed bottom-up actions: European Research Area Networks (ERA.NET), (e.g. M-ERA.NET for materials technology or SOLAR-ERA.NET for solar energy technology R&D).

H2020 is programmed within a structure of the so called biannual Work Programmes (3 in total). Horizon Europe is the next planned research framework program to replace Horizon 2020 in the years 2021-2027 with projected R&D spending levels raised by 50%. The Horizon Europe proposed budget is €100 billion and supports the objectives of the EU Green Deal through R&D in sustainable energy.

5.2. SET Plan

The Strategic Energy Technology Plan (SET Plan) sets the primary agenda for the EU energy technology R&D policy. It enhances coordination of national and European research and innovation efforts to position the EU in the forefront of the low-carbon technologies.

SET Plan involves 10 initiatives, including i.a. wind, hydro, bioenergy, CO_2 capture. But the most prospective are currently priorities in solar power (PV and CSP) under Solar Europe Initiative. It promotes cooperation among EU countries, companies and research institutions, aiming to deliver on the main objectives of the Energy Union Strategy. It consists of the SET Plan Steering Group, the European Technology and Innovation Platforms (ETIPs), the European Energy Research Alliance (EERA), and the SET Plan Information System (SETIS). The EERA joins top research institutes in the European Union specializing in energy research and development. SET Plan closely integrates with all key EU activities in energy R&D stimulation involving the Energy Union Strategy, the Clean Energy Strategy, the H2020 energy area programs and the directions in setting the framework of priorities in renewables for the European Green Deal.

5.3. Energy Union Strategy

The Energy Union Strategy of the European Commission launched in 2015 aims to coordinate through investment and development the transformation of the European energy supply. It is sometimes referred to as the biggest energy project since the European Coal and Steel Community and it is rooted in regional insecurities related to geopolitical use of energy resources by Russia.

One of the 5 pillars of the Energy Union Strategy is research and innovation for the competitiveness in sustainable energy sources and electrical grid capacity that includes PV development. The current budget of the projects involved in the Energy Union strategy is approximately 1B Euro, mainly financed by the Connecting Europe Facility. In 2016 the EC presented a comprehensive research, innovation and competitiveness strategy, which supports the objectives of the Energy Union – the Clean Energy Strategy – outlined in the Accelerating Clean Energy Innovation Communication, where energy R&D is recognized as a driver for 3 main goals: EU as a global leader in renewables, energy efficiency first, fair market deal, which accordingly to the arguments presented above, favors PV R&D.

5.4. European Green Deal

The European Green Deal is a set of policy initiatives by the European Commission with the overarching aim of making Europe climate neutral in 2050 and phase out the fossil fuels as much as possible. An impact assessed plan aims to increase the EU's greenhouse gas emission reductions target for 2030 to at least 50% and towards 55% compared with 1990 levels. The policy aims to make Europe the first climate-neutral continent on Earth.

Compared to the proposed Green New Deal stimulus package of the USA, this EU policy is however criticized with too low rate of decarbonisation of the economy, with the EU aiming to become net-zero within three decades instead of within ten years.

In terms of the support for R&D, primarily in most potentially enabled PV technology the policy strongly leans on the Horizon 2020 Framework Programme for further stimulating the private investment and development driving commercialization of emerging solar cells.

Beyond the H2020 the EU plans to finance the Green Deal through InvestEU investment plan forecasting at least €1 trillion budget. It is estimated that to reach the goals of the policy circa €260 billion a year from 2020 to 2030 is needed. In July 2020 the EU Energy System Integration Strategy was published, paying a lot of attention to the PV technology in terms of electricity self-sustainable systems and the so-called PV smart grid integration.

6. COVID-19 response and role of renewables & PV in the recovery strategy

One of the positive circumstance related to the COVID-19 pandemics (if one can speak at all about positives in face of such tragic events) is related to the climate and pollution. We could all observe how the traffic was nulled in the cities and how the lock-downs had frozen air transport during most of the 2020. A little less noticeable were shutdowns of industry production but these too had a profound impact on temporarily stopping the pollution process. In the energy sector we have all witnessed how in the mid of the pandemic the oil prices turned negative for the first time in markets history during spring of 2020. This was due to the costs of the storage of oil which was not needed to fuel airplanes, cars and factories. This situation unveiled another major vulnerability of physically volumetric fossil fuels which is not the property shared by renewable energy sources.

The peaks of epidemic lock-downs in developed countries reduced energy demand by 25%. Simultaneously the energy spent shifted from physical transport and commuting to home-office surging demand for electricity. This favors sustainable electricity production from renewables. International Energy Agency has predicted in 2020 a 6% drop in global energy demand as a consequence of a global lock-downs due to the COVID-19 pandemics. This is a huge drop, which relatively can be compared to being 7 times larger than the drop after the 2008 financial crisis. This drop in energy demand will primarily hit traditional fossil fuels markets (i.e. coal, oil, gas). IEA forecasts that the renewable energy demand will on the other hand grow by 1%.

There are many initiatives in Europe to make renewable energy a key component of the global economic recovery, driving investment and creating jobs in this sector. The weakening of the traditional fossil fuels markets can be a chance in speeding up the clean energy transition process.

The European Council concluded with EU leaders adopting a statement on the EU actions in response to the COVID-19 (Joint statement of the Members of the European Council, 2020), calling on the European Parliament and Commission to *"prepare the measures necessary to get back to a normal functioning of our societies and economies and to sustainable growth, integrating inter alia the green transition and the digital transformation".*

Renewable energy is thus planned to be a key component alongside digital technology in the COVID-19 crisis recovery stimulus package. Members of the European Parliament approved a resolution calling for a €2 trillion recovery fund prioritising EU Green Deal agenda. Major contribution is planned in grants for i.a. R&D with main focus on PV technology.

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