Teaching PV from basic understanding to global implications

P.P. Altermatt,
Trinasolar Co Ltd, State Key Laboratory for Photovoltaic Science and Technology (SKL),
Changzhou, Jiangsu Province, China, pietro.altermatt@trinasolar.com

Abstract

This paper draws on teaching experiences in three different areas of photovoltaics (PV). Firstly, when teaching the basic understanding of PV, it is efficient for most people if it is taught in such a way that they can briefly summarise the main idea (preferably with a keyword) and assign a picture to this keyword (which best reflects the dynamics of the topic). Secondly, peers in international cooperation are often unaware that they are teaching each other about their contribution to a common project; they tend to think that teaching is something a teacher does. However, if peers spend some time teaching each other, it can improve and accelerate the results of a project. Thirdly, as solar PV becomes a pillar of the energy transition worldwide, it is important to think beyond the technical aspects. To broaden horizons, graphs are presented for group discussions at the beginning of the course, so that participants are not tied into a track, too often prescribed by industrialised countries.

Keywords: teaching photovoltaics, basic knowledge, peer teaching in projects, broaden horizons.

TEACHING BASIC UNDERSTANDING OF PV

How does a solar cell work? To someone who knows that electricity consists of tiny particles (electrons) flowing along copper wires, you may say the following. Sunshine contains energy. In a solar cell, sunlight is absorbed and its energy is given to electrons. These electrons must be transported very quickly to the narrow metal fingers in front of the solar cell, otherwise they lose the energy they have gained. See Fig. 1.

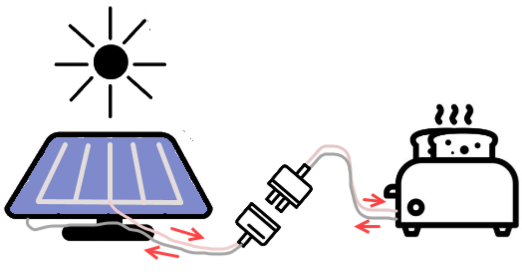

Fig. 1: Electrons get their energy from sunlight and flow through the front wire of the solar cell into your toaster. There, they lose their energy and flow to the back of the solar cell, where they can gain energy from sunlight again.

Once the electrons are in the metal fingers, they flow into the front wire and into your socket, so their energy can be used to power something, for example a toaster. In the toaster, the electrons lose their energy and flow back through the second pole of the plug to the wire at the back side of the solar cell, where they can enter the solar cell and gain energy again. Their roundtrip can start again.

On a next, deeper level, you may talk about more details with the help of Fig. 2, as explained in [1]:

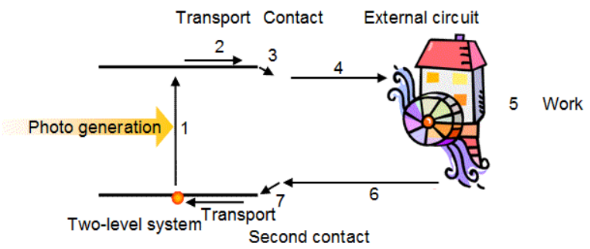

Fig. 2: The pathway in Fig. 1 can be regarded more schematically as a two-level system, with the upper level having more energy than the lower level [1].

From there you may go into more detail. For example, absorption. You may explain that blue light contains a lot of energy (that's why it can cause sunburn), while red and infrared light contains less energy (it warms us up). Then you may show Fig. 3, a two-level system where the upper level has more energy than the lower level:

Fig. 3: Instead of a two-level system in Fig. 2, there must be many levels so that a broad range of colours can be absorbed from sunlight [1].

You may explain that a two-level system (to the left) can only absorb light with a certain energy (or wavelength or pure colour). As the number of energy levels increases (to the right), a wider energy range (or wavelength range or colours) of light can be absorbed. Then you can introduce the conduction and valence band as shown in [1]. Or the advantage of tandem cells. And so on.

The underlying pedagogical method is the following: For most people it is efficient if it is taught in such a way that they can

- briefly summarise the *main idea* (preferably with a *keyword*),
- attach an *image* to this keyword (which best reflects the *dynamics* of the topic), and
- *repeat* it the next day, in a week and in a month so that the new information is memorised.

This underlying pedagogical method is used in the explanations of the photovoltaic principle in [1] as well as in the lecture on the solar spectrum [2] and the lecture on optics for solar cells [3]. These lectures provide small portions of information with a balance between depth (for good understanding) and brevity (to maintain attention).

PEER-TO-PEER TEACING IN INTERNATIONAL COLLABORATION

In international cooperation, peers often have difficulties informing each other about their contribution to a joint project. These difficulties arise when peers cannot visit each other either because they live on different continents or due to covid travel restrictions. Fig. 4 shows a real-life example where a peer describes on three PowerPoint slides how he/she examined samples from the other peers (for confidentiality reasons, some details are asterisked).

The sample structure is simple: there are a maximum of four different layers evenly deposited on a silicon wafer. However, the project was plagued by misunderstandings between the peers who deposited the layers onto the wafers in one country and the peers who examined the results in another. An analysis of the report in Fig. 4 showed that the experiment itself was described in sufficient detail, but both peers were not quite sure about the identity of the samples. Moreover, the peers who had deposited the layers were not sure what the other peers had concluded from their experiment with etching. They were also not sure how to proceed with the next round of samples.

Both peer groups were given the following recommendations to not only inform each other but to teach each other about their own work:

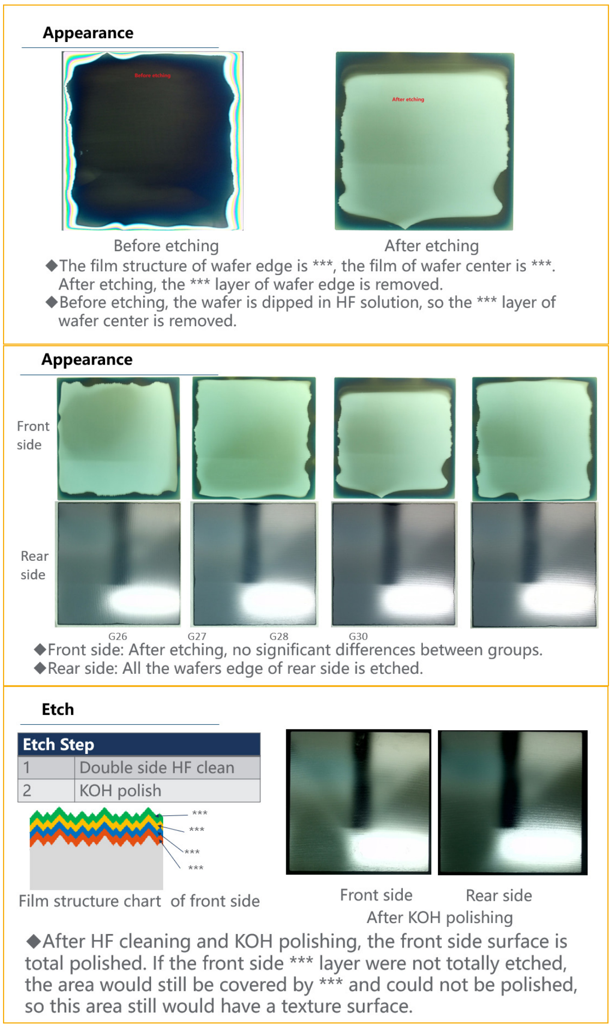

Fig. 4: A real-life example of how peers report instead of teach their experiment on samples treated by peers in another country. While the experiment itself is reported in detail, the context, the goal, the conclusions and the way forward are not communicated, leading to misunderstandings and uncertainties.

1. Give *context* on the first PowerPoint slide. What is your specific *goal* for this series? What is your *problem* that you want to solve? This was missing in Fig. 4.
2. On the second slide, make sure to communicate the *identity* and *structure* of your samples and the *tools* used for a measurement etc. to avoid misunderstandings that can also occur later when comparing different experiments as part of a common project. The structure of the sample was incompletely described on the last page of Fig. 4.
3. Describe your specific *work* (well done in Fig. 4).
4. Add your *results* explicitly (they were only implicitly communicated in Fig. 4).
5. Communicate your *conclusion*, which is your *interpretation* in the context of the first slide. This was missing in Fig. 4.
6. Finally, add instructions or suggestions on *what to do next*, i.e. what you think is *useful* to get closer to your *goal* described in the first slide. This was missing.

If you describe more than just your experiment, it will help the other peers to get closer to your goal. If they don't know what your goal is, they will automatically pursue their own goal.

For an online meeting, all PowerPoint files of the past experiments were sent to all peers again and then discussed one after the other. It turned out that there were not only misunderstandings from the beginning, but also that the goals of the two peer groups diverged over time.

Reflecting on what happened over time, it turned out that the two peer groups were unaware that they were often in a *teaching* situation. Teaching is often seen as something teachers do. However, spending some time on good peer teaching can improve and accelerate the results of a project.

In short, routinely communicate your contributions to a joint project as follows:

Context:
- Goal
- Problem

Experiment:
- Identity of samples
- Methods used

Interpretation:
- Results
- Interpretation
- Conclusion

What to do next:
- What is useful to get closer to the goal

TEACHING GLOBAL IMPLICATIONS OF PV

Photovoltaics is becoming one of the main pillars of the global energy transition to reduce CO_2 emissions and fulfil the Paris Climate Agreement. For this task to be accomplished, it is important not only to think about the technology. As with any technology, it involves people and affects people.

This implies two aspects of teaching:

1. Teaching ourselves how the use of PV affects people, their economy and the environment.

2. Teaching people about PV, its uses and its impact on their lives.

In the following, a very general and open entry for the first point is addressed by presenting a series of simple graphs to a small group, one graph after the other in a time span of about 5 to 10 minutes each. This is intended to stimulate a discussion about the causes of the global energy system and possible impacts of PV.

For simplicity and to avoid being distracted by regional details, all graphs are plotted against geographical latitude, where 0 is the equator and ±90 is the north or south pole.

The first graph compares population with energy consumption:

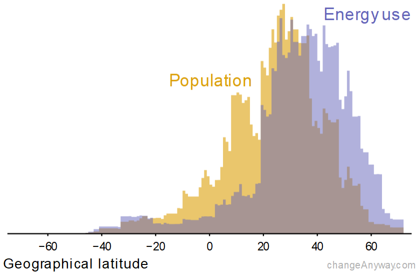

Fig. 5 Energy consumption compared with population across geographical latitude, where 0 is the equator and ±90 is the north and south poles. The area under both curves is made equal.

The first reaction may be that the gap between population and energy consumption is because more heating is needed in the north. But soon a discussion may emerge about rich and poor countries and how to alleviate the world's energy supply problems.

After 5 – 10 minutes, the next graph is handed out, which compares the population with fossil energy production rather than with energy consumption:

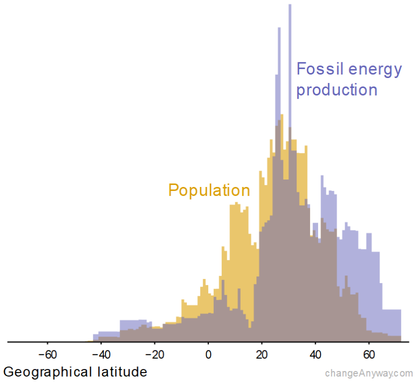

Fig. 6: As Fig. 5 but comparing population with fossil energy production.

People may ask themselves first, where the two different peaks of fossil energy production come from. It is oil production, limited to a very few countries. It is often surprising that there is a disparity between population not only in energy consumption but also in energy production. The populated south not only consumes less energy, but also produces less energy. A discussion may arise about how energy production will develop in developing and emerging countries and what impact this will have on the Paris Climate Agreement.

The next graph is about the realistically assessed potential of PV in each country in terms of connection to a grid or the distribution of stand-alone systems, the distribution of the population within the individual countries, the locations for industry, etc. (which differs considerably from "country area times annual irradiance"):

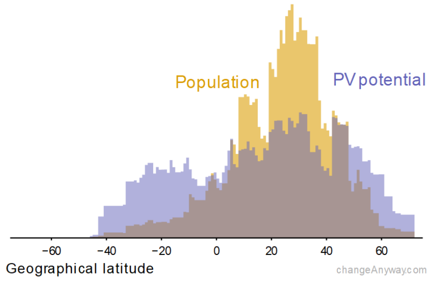

Fig. 7 As Fig. 5 but comparing population with the realistically achievable PV potential.

At first, one might be surprised at the low PV potential compared to the population between 0° and 40° north latitude, and the high PV potential at high latitudes. An important clue for the group could be that we do not need to exploit a large part of the PV potential to be fully provided with energy, and that at high latitudes the PV potential is high relative to the population density because the population density is very thin. There may be discussions about seasonality, or whether Australia's high potential can be used in a hydrogen economy, or what happens in India (which stretches from about 10° to about 30°). The peak of population density is where India and China overlap in latitude, both fast-growing economies with a high share of coal power.

From there, more detailed and specific discussions may develop and the teacher may begin to teach more concrete elements with more concrete graphs and topics.

If you teach more concrete topics after these graphs, you have to expect that people will criticise you for leaving out this or that topic. This is a good sign: The graphs shown here are intentionally less concrete in order to *broaden* the horizon in group discussions and to think of all possible aspects that you as a teacher cannot cover all. If you start the lesson right from the beginning with the usual graphs about the global state of energy, population, industrialisation, etc., people are already tied into a track. A non-specific introduction broadens the perception, and as long as you don't spend too much time on it, people won't find it too vague, but an open introduction to a complex topic that is too often taught in a limited way, prescribed by industrialised countries.

ACKNOWLEDGEMENTS

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