OPEN SCIENCE: NEW CHALLENGES AND OPPORTUNITIES FOR THE PV SECTOR.

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ABSTRACT: The concept of Open Science (OS) embraces a great number of practices targeted to promote more transparent and reproducible scientific processes. This, combined with the implementation of public engagement processes from the research community, drives us to a more collaborative and accesible science, where the chance of generating systemic and disruptive innovations can grow exponentially. In this work we show how a group of researchers have designed a methodology for assisting engineering researchers in the adoption of Open Science. This methodology is being applied along the full research cycle to produce six research outputs in the Photovoltaic (PV) field: a PV ageing model, an in-situ repairing methodology for PV modules, a PV-assisted irrigation system, PV heat pumps, a novel micro-concentrator system. and three-terminal tandem solar cells based on silicon and perovskites. We show how we are putting an Open Science approach into action in such research activities, so that PV innovations are better aligned with the society's expectations, needs and values, enabling at the time more reproducible, transparent and collaborative science.

Keywords: Open Science, Dissemination, R&D and Demonstration Programmes, Sociological perspective, Water-Pumping, High-Efficiency, System Performance.

1 INTRODUCTION

1.1 An urgent claim to generate systemic innovations.

In June 2018 the new research and innovation framework programme of the European Commission (EC), Horizon Europe, was announced. Since then, we have been getting to know some details on its features, structure and objectives. This new research and innovation scenario for the period 2021-2027 brings good news for our sector: scientific activities on renewables energies in general and on photovoltaics in particular, are called to play an important and a decisive role within a Programme where 35% of the total budget is devoted to tackle climate change. New and disruptive ideas, research activities to improve and push forward current technologies, as well as innovation actions to foster and strengthen market deployment, will be financed. However, the European Vision of **creating more impact through mission-orientation and citizen involvement,** and **reinforcing openness** will be at the core of all the calls launched within the new Programme. Therefore, the chance of performing relevant research activities in a more responsible way will not be optional anymore but a mandatory requisite for those who want to win Horizon Europe Grants. Surely, national governments will follow the holistic European attitude and will start to request practices to support such vision in their own R&D Programmes.

Researchers must be competent and trained for the new scenario and EC knows it. One of the initiatives supported by the EC for helping researchers to face up in a short term this new approach about Citizen Involvement and Openness is the GRECO Project. **GRECO is here to demonstrate to researchers working on any of the seven societal challenges areas of Horizon2020 how these new requisites can be implemented within a real research project** in a plausible way.

1.2 Responsible Research and Innovation (RRI)

It is important to understand the so-mentioned European Vision prior to any attempt of adopting "fancy" terms just for winning some points in the future proposals. The reader must be aware that the new strategy is consistent with a general frame called Responsible Research and Innovation: Rome Declaration [1] defines Responsible Research and Innovation, RRI in short, as *"the on-going process of aligning research and innovation to the values, needs and expectations of society*". In an attempt of paving the way to its practical implementation, social scientists identify six pillars in RRI: 1) Gender Equality, 2) Ethics, 3) Science Education,

4) Governance, 5) Open Science and 6) Public Engagement. So, by taking proper actions in each of these pillars we will align our research and innovation processes to the needs, values and expectations of our society.

We are aware that many R&D practices already pay attention to some aspects within the RRI concept. For example, for a long time researchers have been dealing with Ethics matters in projects such as Consortium Agreements, Informed Consents Sheets, integration of third countries into research projects, communication of any dissemination action to the Consortium prior this takes place, recognition of ideas -quotes-, etc. Or with Gender Equality aspects such as including women-led teams, balancing the consortiums, fostering the visibility of women in science, etc. However, significant improvement is possible, especially in considering the holistic approach provided by RRI, and fostering the non-fully exploited concept of Open Science and Public Engagement.

1.3 Understanding Open Science

And, what is Open Science? According to Michael Nielsen, **"*Open Science is the idea that scientific knowledge of all kinds should be openly shared as early as is practical in the Discovery process*".** Where **scientific knowledge of all kinds** refers to journal articles, data, code, online software tools, questions, ideas, speculations, failures,… and anything which can be considered knowledge. Nielsen remarks **as is practical:** despite the fact that we are due to follow some contractual conditions (i.e. H2020 requests a maximum embargo period of six months for scientific papers), if considering the whole dimension of the application of Open Science very often there are other factors: legal, ethical, social, etc., that must be considered.
However, it is also true that for some experts, **Public Engagement and Citizen Science**, both concepts related to the citizens involvement in science, **are not separate concepts from Open Science** as defined by the Rome Declaration. They understand that the first openness and attempt to perform more responsible science is to conduct and operationalize quadruple helix knowledge coalitions in research projects where researchers, policy-makers, industrials and citizens work together and share knowledge to foster innovation. GRECO supports this understanding of the Open Science concept.

2 METHODOLOGY

2.1 Definition of a rationale for implementing Open Science in Technical Research activities.

GRECO has defined the *lightflash* model depicted in Figure 1 as a rationale pilot to guide researchers on the practical implementation of Open Science. To define such pilot GRECO researchers have had to adapt the theory on Open Science to the features of technical scientific activities, while learning from some practical demonstrators conducted by social science researchers regarding public engagement. Therefore, our interest in promoting an understandable and practical Open Science rationale stems from our struggle to overcome in a reasonable manner the same fears, doubts, hesitations and concerns that any of our counterparts might have when reading the extensive (and sometimes idyllic) literature on Open Science.

GRECO rationale boils down on three main concepts. The first assumption is to consider that Open Science is not an isolated term but is one of the six pillars of the Responsible Research and Innovation approach. Hence actions such as Responsible Governance, Public Engagement, Ethics or the Gender Dimension, must be also taken into account when planning a research project integrating Open Science. The second assumption relies on the idea of being applicable for any kind of research process. regardless its technology readiness level (TRL). And the third principle considers that openness can be practiced at any of the stages of a research project, not only in the "action" phase.

Built on such premises, any researcher can adopt the *lightflash* model by using those elements that fit better with their domain or interests. This flexibility is relevant, since one size does not fit all, in particular in those situations where the adoption of some Open Science practices might be a dilemma: in fact, we cannot forget that adopting Open Science must not preclude the obligation of researchers to protect results, to maintain confidentiality, to look after security matters or protect personal data, which have to apply as a primary obligation.

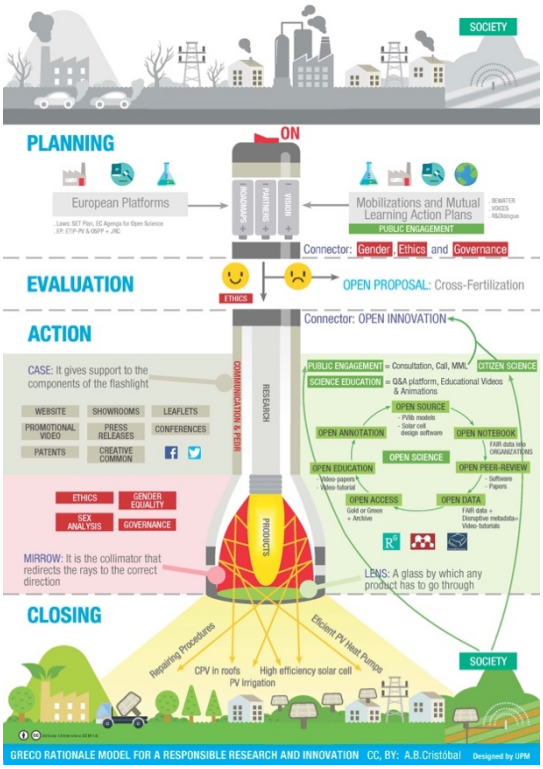

Figure 1: GRECO rationale model for responsible research and innovation [2].

From the point of view of the availability of practical tools, Bianca Kramer and Jeroen Brosman have been able to classify more than 400 tools into a full and complete rainbow of 17 open science practices, understating Open Science in the more stricted academic definition. This classification, shown in Figure 2, goes beyond the eight open science practices proposed by GRECO in its rationale model: Open Proposal, Open Source, Open Annotation, Open Education, Open Notebook, Open

Peer-Review, Open Data and Open Access. GRECO decided to focus on the most relevant ones for engineering domains mainly due to practical reasons.

The point is that although the spectrum is wide, **the system is not ready so far to have a fluent workflow with Open Science practices adapted to researchers' needs**. Currently, some of them, that are even mandatory under the majority of the European Research Funding schemes (such as Open Access and Open Data) do not count with a clear support, neither from the technical nor the financial points of view. We are here criticizing two issues.

Firstly, a lack of infrastructure and resources is notably when researchers approach Open Data, where inconsistences and contradictory suggestions are the general rule at the moment for the majority of the scientific domains.

And secondly, we are against the idea of including Open Science, mainly Open Access, support funds under the same financial slot devoted to scientific research, since this reduces the budgetary availability for "doing science". And although some Research Agencies increase funds for R&D yearly, which is not the general case, the reality is that the requirements for publishing in Open Access add additional burden to the limited research funds. This is particularly sensitive for an R&D system that evaluate its researchers against the number of written papers in high impact journals, where Article Processing Charges or Gold Open Access fees are about €3,500. And, extremely critical, when R&D Institutions adopte the mandate for all their researchers to publish in Open Access regardless the financial support and funder they have.

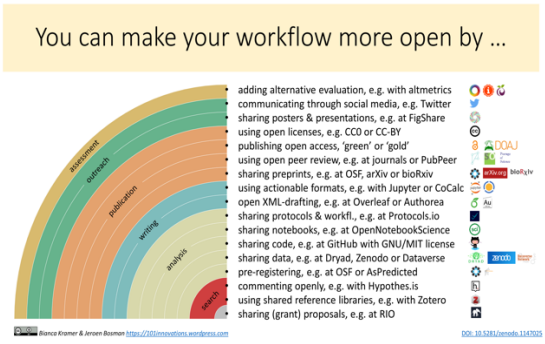

Figure 2: Rainbow of Open Science Practices and Tools. Image under CC-BY 4.0 license taken from [3].

So, by overwhelming technical researchers with a lot of suggestions that do not work 100% properly when they demand quick, effective and efficient tools, rather than encouraging the adoption of Open Science approaches, in our opinion it will cause the opposite effect. This is the reason why GRECO decided to reduce the spectrum of tools in its rationale.

2.2. GRECO Lightflash allegory for OpenScience

The *lightflash* model is an allegory. According to that scheme, batteries or precursors of research activities must include not only the capabilities of partners and roadmaps stablished by Governments and Industries, but also gathering the vision and insights from the civil society and citizens obtained thanks to different methodologies: world-cafés, focus groups, reversed science cafés, science-shops, etc [4]. Once we have planned our research activity considering also Ethic, Gender and Governance aspects, and the proposal is granted, GRECO claims for more transparency in the evaluation and funding processes. From the researcher side, we consider that the correct way of screwing the batteries to the rest of the flashlight is by sharing and opening granted proposals [5], so everybody can know what exactly is being funded by each National or International Agency, avoiding double funding as much as possible and enabling open peer-reviewed granted projects. The Development Phase contains several elements and we will not be able to get light without the correct performance of them. The wire is "the research" that. connected to the bulb. gets a lot of "products" or scientific outputs. Both wire and bulb are hold by a case that is the communication and dissemination plan. However, light rays (i.e., "the products") only can illuminate efficiently if they are redirected in the right direction thanks to the collimator and the lens. Thus, in research we only can align our products towards the needs, expectations and values of society if we adopt RRI methodologies in general, and Open Science in particular.

3 RESULTS

GRECO is just a first demonstrator, obviously there will be room for improvement as long as we walk this new way all together. Our objective is to show a possible and feasible way for the practical implementation of Open Science in engineering and technology related projects. Fortunately for our sector the GRECO pilot is tested in the framework of a project that pursues the development of several **products in the field of photovoltaic energy**, which, undoubtedly will facilitate a quicker understanding by the PV community of the new scenario of openness requested in Horizon Europe. Thus, the pilot on Open Science Methodologies into Practice, is being tested in a research line related to the **ageing modelling, characterization and repairing of PV systems**; in a second one devoted to **irrigation PV solutions** and; in a third one, related to **next generation PV concepts**, that includes: *PV-Heat Pumps, novel solar cells and micro-Concentration PV systems (μ-CPV)*. This wide range of technologies allows GRECO to provide case studies for the implementation of Open Science practices for PV products on different technology readiness levels (TRLs).

3.1 Open Science for Circular Economy Innovations on Photovoltaics

In this line of work, the researchers tackled the challenge of carrying out an aging model of photovoltaic modules. It is true that these models exist in the sector, but it is also true that they are based on numerical predictions that suppose a linear degradation of the power of the systems. These simulations that are used, for example to determine project financing due to the diligence of large PV plants, lack a validation of the data on which the model is based. And the experience of more than 30 years of GRECO researchers in the evaluation of PV plants led us to think that the models have a lot of room for improvement.

Thus, the consortium understood here the social connection to make socially-responsible innovative products as the opportunity to be able to make an aging model based on actual production data of PV

installations. But the challenge was not easy considering that only 1% of the worldwide PV installed capacity is older than 15 years.

Hence the Open Science principle of engaging citizens and civil society in research has come to a public call launched in January 2019 and the voluntary engagement from 120 European private PV installations which are older than 15 years. This will produce **the first PV ageing model based on real data, and also a repairing PV modules in-situ methodology tested for a large casuistry of defects that we are finding out in such elder installations**. It is estimated that a 10% of the PV modules failures are due to reasons which cannot be attributed to the manufacturers. And thanks to the open approach, our methodology will be openly distributed through an open tutorial, so installers from any part of the world can use it.

This research activity will also show how the OS rationale model must be "adapted" to each specific situation. And, although the repairing methodology and the ageing model are open products themselves, here the application of Open Data, one of the Open Science flagships, is not possible. This is a perfect example on how data privacy from PV installations owners must dominate to any other interest. And the chance of becoming them into anonymized data is not useful, since anonymized data are not providing the traceability and information requested for reusing such data in science, either for verifying our own products or for their utilization in further applications.

3.2 Open Science for PV-assisted Irrigation Systems.

Another of the GRECO lines tries to provide more sustainable energy solutions for the irrigation communities of the Mediterranean basin. The current problem of the sector is twofold: on the one hand governments demand better water management and on the other, farmers require energy systems that do not penalize them for high use at specific times of the year. GRECO put on the table several alternatives to develop technologies that solve this need.

The novelty here is that GRECO has not decided on its own what to do, but jointly with irrigators from Italy, Spain, Bulgaria and Portugal, regional governments throughout the Mediterranean basin and irrigation companies, making a process of Open Innovation a reality. In these exercises, in which impressions were exchanged with all these social agents, the possible technical solutions to work on and the essential characteristics demanded from them were prioritized. Thus, GRECO is developing what they considered most relevant: the development of a solution for irrigation systems with more than 20 PV modules in series, and the design of PV irrigation system configurations for pumps of more than 400V.

At the moment we have developed an algorithm to analyze and quantify the PV energy losses produced in PV irrigation systems depending on the number of PV modules in series that is implemented at the SISIFO open simulator [6]. Thanks to such algorithm, GRECO researchers designed **a solution for PV irrigation systems with more than 20 PV modules in series**. This solution, whose main focus is to overcome voltage limitations, relies on avoiding the PV generator being in open-circuit by installing a small-power load from the sunrise until the open circuit voltage is less than 800V. This load can be the air-conditioning system that already exists to control the temperature of the frequency converter box. A PLC, a switch, and an additional frequency converter/inverter must be added to the system. The solution is ready to be implemented by the interested users and it is described and available in an open scheme at [7].

3.3 Open Science related to next generation concepts

The remaining three products are intended to improve the integration of photovoltaic solar energy into the electrical system, and in particular in the urban environment. To do so in an OS framework the values, expectations and needs from citizens should be address, and the question is: how to identify them? To this end, mutual learning dynamics have been carried out in six different countries, fostering dialogue between companies, administrations, researchers, associations and citizens, to analyze the demands made from each sector and to begin to imagine the elements of the next generation of PV products. We are currently in a process of information curation, and the full report will be soon at the GRECO Community into ZENODO repository [8]. We can already outline these three main general conclusions:

- There is a lack of information and even misconceptions about PV technology which could be overcome by improving communication between research and society, and by interdisciplinary research.
- The energy transition should be supported by governments, but individuals need to be included into the decision-making process.
- PV technology should be clean, recyclable, accessible, of high quality and well adapted to installations' surroundings.

Therefore, the technologies that GRECO is developing for the integration of PVaim at supporting some of the expectation on products capabilities commented during such dialogues.

On the one hand, cheaper and more efficient solar cells are being developed, combining the dominant silicon technology with the promising technology of the perovskites. It is well known that this technology has a great potential, but also a point that participants on the dialogues commented: *"Photovoltaic Technologies cannot have the sin of other technologies.* ***Stop from thinking just on increasing efficiency and saving money at any cost. Recycling must be always the last option instead of the excuse to create a new environmental problem****",* when talking about the inclusion of some materials such as Cd or Pb in solar cells.

This is a hot topic of research today, and GRECO wants to contribute from the Open Science perspective to such society expectation empowering researchers with due Open Tools. Thus, firstly, GRECO will rehearse a strategy to share scientific data from perovskites in order to generate a common database to inspire progress towards more efficient and sustainable materials [9]. At the time, GRECO is considering the idea of increasing efficiency just by using other solar cells architectures for perovskites, in particular the use of the three-terminal hetero-junction bipolar transistor solar cell [10]. Although the implementation of the idea is very ambitious, this will be supported with modelling through an open source program that will be openly accessible to the rest of the scientific community. Needless to say that this research activity is continuously supported by Open Access and Open Data practices that can be found in the library of our project at

Zenodo [8].

GRECO is also supporting the development of micro-concentration solar modules which thanks to its high efficiency will produce a lower footprint at terraces and roofs, being able to cover the whole energy demand of residential buildings of up to 8 floors. GRECO has recently validated a 29% efficiency of this technology and has already opened the measurement protocols and the characterization data that support this validation, in that exercise of transparency that Open Science pursues, and as way to establish quicker comparisons with other technologies [11,12]. However, GRECO here is demonstrating how Open Science can be performed while maintaining the European competitiveness, and while the company developing this technology is sharing with the scientific community the measurements and protocols, they keep those critical features under patents and secret, which is understandable and in line with the innovation system as a wheel of the economy.

And the latest technology we are developing lies on the idea of using PV systems for heating pumps, which was also commented as a society expectation in some of our dialogue events. We are investigating control algorithms, sizing procedures, and new hybrid systems, and making the results open to the sector [13]. Within this line, we will explore soon if Open Peer-Review processes are suitable for our area dynamics.

4 MANAGING RESEACHERS' FEARS, DOUBTS AND CONCERNS ON OPEN SCIENCE.

GRECO has held several meetings and workshops with researchers from different scientific domains in order to explain our experience and the flashlight methodology. From such events, at the moment more than 100 researchers have completed an exercise specially designed to raise a public understanding on the drivers and difficulties that researchers have when they think of adopting Open Science approaches in their daily activities. These exercises are still being carried out, and they will be exploited soon to generate the GRECO Practical Open Science Guide, which aims at being not an Academic Guide, since there are good resources freely available on the internet, but also a FAQs guide trying to give response to the reluctances, fears and concerns that these researchers have mentioned. GRECO thinks that just by listening to the final users of Open Science methodologies and providing them adequate responses to their feelings, Open Science will have the chance of being accepted in a voluntary basis rather than imposed by Funding Agencies. If you are interested in collaborating in this exercise, your inputs will be welcomed until the end of January 2020, by contacting the corresponding author of this paper, who will give you detailed directions on how to carry out this 30-minute exercise.

5 BENEFITS FROM APPLYING OPEN SCIENCE.

Benefits from Open Science approaches are wide and differ from one party to another party. Thus, for researchers there are social studies proving that the adoption of Open Science approaches ends up with major credit, visibility and networking capacity. For research teams, just the chance of transferring to the public domain part of your research outputs for being reused is a practice that in one hand adds value to public money obtained from citizens' taxes, while in other hand increases the chance of coming up with new innovations quicker. For policy makers, Open Science approaches allow them to be make better informed decisions, increasing at the same time the impact of funding. And for citizens, Open Science approaches generate trust on science at the time that science benefits from a well-trained society with a real interest on being part of the scientific movement.

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