

## Article

# Towards a Sustainable Future through Renewable Energies at Secondary School: An Educational Proposal

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**Abstract:** A compilation of innovative educational activities to work on concepts related to the production of electrical energy is presented. To approach the real-life secondary education curriculum, they are grouped to be performed during a week denominated Renewable Energy Week: an educational proposal aimed to promote the respect for the environment through the insight on Sustainable Development Goals (SDG) and renewable energy sources. The students would build and perform low-cost experiments so as to deeply understand the essence of energetic transformations, as well as electricity generation. Learning by discovery, collaborative learning and experimentation, are the methodological pillars that characterize Renewable Energy Week, since they have been proven to be efficient methodologies to promote students' learning. Innovative techniques for pupils evaluation are employed, including a rubric, *Socrative* application and a set of sheets regarding experiments. Through this educational proposal, the students are expected to achieve a deep understanding of some key concepts related to electricity and awaken their interest in scientific subjects, making them conscious of the transition to sustainable development that our planet urgently requires. At the same time, this project offers to teachers a series of experiments and innovative activities to work on the SDG in Physics, Chemistry and Technology subjects.

**Keywords:** low-cost experiments; Sustainable Development Goals (SDG); renewable energy; secondary education; collaborative learning; *Socrative*



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## 1. Introduction

Current society model leads us to reconsider certain aspects about how we are living. "Education" and "Environment" are two of the main concerns at the present and they are closely tied. There is an international responsibility about promoting, from early stages of education, the awareness related to sustainable development [1]. The goal of living on a sustainable planet strongly depends on the education of future citizens in the values of sustainability and respect for the environment.

In this last decade, those issues has been specified through the establishment of Sustainable Developments Goals (SDG) proposed by the United Nations [2].

SDG are composed by a set of statements intended for all world population, aiming to improve both fields previously mentioned, among others. The SDG number 4 that states: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all", and the SDG number 7: "Ensure access to affordable, reliable, sustainable and modern energy for all" are the major driving forces behind this article.

As Martínez-Borrego et al. [3] establish, energy is a key concept of sustainability within environmental education. She concludes that although energy is a wide concept within Spanish curriculum more action is required to promote sustainability at all stages of the education. Thereby, learning how energy generation systems work, their advantages and shortcomings and improvements will likely contribute to create a sustainable society.

This paper contains a compilation of experiments and innovative activities to work these concepts. To get close to real life education, they are organized as a complete activity developed during a week. As Çoker et al. [4] expose, there is a need of contextualizing energy concepts in school curriculum for increasing the awareness on environmental issues. He also claims for practical applications and real-life based projects as well as performance work. Furthermore, as Lucas, Pinnington and Cabeza [5] point out, there is an urgent necessity of professionals for creating a workforce supporting renewable energies. Most of them are instructed for installation and O&M tasks, but in the near future they will be required to posse some skills such “environmental awareness and a profound understanding of sustainability” then, education on SDG is needed, as we propose through our activities. To attach this, an educational proposal named Renewable Energy Week has been designed. It consists of five sessions in which secondary school students will meaningfully and functionally learn the basis of different renewable energy systems through the performance of low-cost experiments. Additionally, collaborative learning and learning by discovery methodologies are employed aiming to turn the students into active agents in their own learning. Rodriguez-García et al. [6] conclude that there are a reduced number of exploratory studies which could give a holistic view of education for sustainability, concretely in regard to the development of the curriculum and the teaching-learning process, especially at compulsory educational levels. On their part, Zguir et al. [7] expose that SDG suffers lack of acknowledge to be included on the curriculum and teachers has not the proper notions on the field. That is the reason why it is presented not only as a collection of experiments but a complete and integrated activity to facilitate teachers implementing it on their subjects.

This project is framed within the Spanish educational law “LOMCE” (Organic Law for Enhancing Educational Quality, *Ley Orgánica para la Mejora de la Calidad Educativa*) [8], which is widely specified in Castile-Leon regional law “ORDEN EDU/362/2015” [9]. Therefore, the contents attached along the proposal are directly related to these educational laws, intended to secondary schools students. Concretely, 3° E.S.O (third course of compulsory secondary education) is taken as the reference course for this proposal, which is equivalent to Key Stage 4 (KS4) [10] at British system education, or 9th grade of high school level within American system education [11]. “Renewable energies” itself occupy a very limited space within the Spanish compulsory secondary school curriculum, which constitutes another compelling reason to develop this project. Concretely, there are only four compulsory subjects at secondary education in which energy is tackled from a sustainability point of view [3]. While studying renewable energies, many other concepts must be approached, such electricity, magnetism, energy and its forms, engines, etc. Physics and Chemistry, together with Technology, are the subjects which encompass those concepts. However, it is to note that this is a proposal that can be used in other educational levels and implemented in a different way.

Innovative methodologies will be applied on these activities, such as learning by discovery, collaborative learning, experiments, etc. Learning by discovery, according to Bruner [12], implies not only to understand subject key concepts, but also to develop an inquiring and reflexive attitude towards it. The latter directly leads to mature high order cognitive skills, as those described by Bloom [13]. Synthesis, Evaluation and Analysis are the three advanced skills in Bloom’s taxonomy of knowledge. They are also some of the cognitive skills demanded by the Spanish curriculum for learning the concept of energy from a sustainability perspective [3]. Bruner also claims that learning by discovery can serve as a way to motivate the pupils, since learning turns into a kind of challenge with questions that the student must solve mainly on his own. This methodology is closely related to experimentation. As Oliver-Hoyo et al. [14] demonstrated, by using experiments in Physics and Chemistry lectures, the students got more involved with the subject and consequently, learning was more effective and autonomous. Jiun et al. [15] also proved that experiments, together with lectures, helped the students to develop high order cognitive skills. Furthermore, Renewable Energy Week activities seek to be adapted



to different learning styles and intelligences in order to achieve a higher performance by the students. Tolomeiu et al. [16] proved this, and they also concluded that self-confidence and motivation was enhanced when classes suited different learning styles.

Besides experiments and learning by discovery, Renewable Energy Week would also make use of collaborative learning. This methodology can lead to academic success from different perspectives: intrinsic or personal motivations, extrinsic or “reward system” motivation, group cohesion and positive interdependence. When a group of students work together to achieve a common purpose, each of them with different but essential tasks, positive interdependence and social and civic competence are promoted [17]. The fact of assigning diverse tasks, i.e., different “roles” in the group, enhances “learning to learn” competence as well as student autonomy, since each member must find their own information and then share it with their fellows [18]. Du et al. [19] implemented Project-Based Learning (PBL) methodology (which include collaborative learning as one of its main approaches) at university level for enhancing sustainability curriculum. They obtained promising results in regard of the students involvement and their skills development.

In regard of assessment, Serrano de Moreno [20] states that the evaluation of learning must be formative, qualitative and integrated in the pedagogical process as well as in all teaching experiences, doing it permanently. With the aim of evaluating the activities Socrative, “scientific sheets” and rubrics are used. *Socrative* is an on-line platform for quiz implementation [21]. It provides instant results and statistics from the pupils answers. According to Santos et al. [22], many authors conclude that “audience immediate response” systems possess a great deal of advantages: higher motivation and involvement on students part, quickly diagnosis about pupils knowledge and they also promote collaborative learning. Together with *Socrative*, it is intended to use a set of question sheets, named as “scientific sheets” for the activities assessment. This resource, with a short report format, has a double aim. On one hand, it intends to encourage “linguistic competence” for the students to express their ideas through written language, promoting thus literacy in science. The latter is of great relevance, since scientific literacy is not only needed within an academic scope, but also at social and political level as Ezquerro-Martínez et al. [23] analysed. On the other hand, as Espinosa et al. remark [24], the report has the purpose of combining theoretical concepts and practise. Thus, students could become aware about the considerable importance that theoretical concepts have on science.

Rubrics are also used, because they are known to permit an objective assessment of learning and facilitate peer correction [25]. Rubrics also allow to assess aspects beyond knowledge itself, such as competence acquisition. Attitude towards the proposed activities and towards their colleagues, effort during sessions and technical language level are some of the qualities of pupils that cannot be evaluated by a simple quiz. Furthermore, rubrics let students know “*a priori*” the criteria to obtain the highest mark. This is a way for the student to be “self-evaluated” [26], checking until which extent they have achieved the objectives established within the activities. The assessment tools previously presented intend to be “qualitative” more than “quantitative”, giving priority to the process instead of the results. Hernando Calvo also remarks that the truly important thing for the students is the clarity at the time of presenting them how the evaluation will be [27].

Therefore, the main objective of this article is to compile a series of experiments and activities that allow to work in depth on the subject of energy production. For its presentation, the material has been organized over a week to promote renewable energy, thus facilitating the teaching work in their lessons. With all this, it is also intended to promote the SDGs, specifically objectives 4 (quality education) and 7 (affordable and clean energy). Boosting the interest young people have on renewable energy sources and demonstrate the utility and real world applications of science subjects contents are two of the secondary aims of this project. It is also intended to deepen and widen some scientific concepts which sometimes are difficult to understand without a visual support. Finally, this educational proposal seeks promoting the respect for the environment as well as awaking teenagers interest on research by developing its creativity and critical thinking.

The educational proposal will be explained in detail along the next paragraphs. Firstly, Section 2 includes the methodology, the evaluation and the organization of each session, compiling the bulk of the information about the project. Finally, in Section 3, the main conclusions extracted from this educational proposal are exposed.

To conclude the introduction, it must be known that due to the pandemic of coronavirus disease (COVID-19), this project could not be implemented. It was going to be performed during 2019–2020 academic year and although it has not been put into practise yet, the authors are working on it.

## 2. Materials and Methods

On the basis of the literature reviewed in the introduction, the main objectives of this project can be itemized as follows:

- Gathering experiments carried out with simple materials to work on concepts related to the production of electrical energy, specifically renewable energies.
- To offer teachers a series of experiments and innovative activities to promote the Sustainable Development Objectives in Physics, Chemistry and Technology subjects.

From them, some secondary objectives are derived:

- It is intended to expand students' knowledge about renewable and alternative energy.
- To promote respect for the environment through the insight on Sustainable Development Goals (SDG) and renewable energy sources.
- Put into practice efficient methodologies to enhance student learning: discovery learning, collaborative learning, along with experimentation.
- To employ innovative techniques for student assessment: rubrics, use of the *Socratic* app, and a set of flashcards on the experiments in each session.

Along this section, the methodology, activities and experiments selected are depicted. The implementation design aims to approach the real-life Spanish educational curriculum and to enabling its embedding within the academic activities. However, this project could be directly adapted to the peculiarities of other countries educational systems.

### 2.1. Methodology: Learning by Discovery, Experiments and Collaborative Learning

According to D. Ausubel, "meaningful learning" could be defined as the acquisition of new knowledge consistently to the previous concepts that students already have and understanding them on their own words (i.e., not literally) and being thus, conscious of what they learn [28]. In order to achieve a meaningful learning on the part of the students, three methodologies are combined in this project: learning by discovery, experiments and collaborative learning.

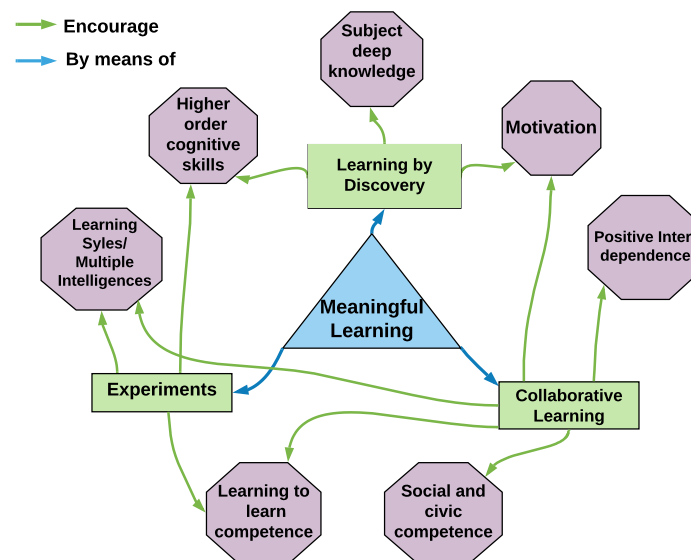
In Figure 1, a summary of the methodology that will be employed at the Renewable Energy Week is depicted.

At the beginning of each session, students will perform some experiments that may awake their curiosity, since daily life objects serve to create experiences related to the course contents. Thus, pupils are hoped to attain a significant learning.

During the introduction of the first session, the students will be divided in groups. There will be different roles, that is to say, a specific and different function will be assigned among the students within the group. Roles rotate along the sessions. The proposed roles are enumerated below.

- Two "Engineers": They are in charge of the project construction corresponding to the session (selecting the materials, the pieces, the way of assembling them, etc.).
- The "Scientist": The student within this role must complete the "scientific sheet" related to the session, including the steps followed to craft the project as well as some questions related to its scientific basis.
- The "Reporter": His aim is to recompile relevant information from the Internet so as to expose it the last day of the Renewable Energy Week. That information must be translated into pictures, photos, schemes, etc. They will also be in charged of

elaborating the scientific basis for presenting it in a simple and clear way during the projects expositions. This student should also help the “Scientist” to complete the “scientific sheet”, since there will be a specific section for the information found. The latter also serves as an evidence of his participation.



**Figure 1.** Summary chart of the combination of methodologies employed in the Renewable Energy Week.

During Renewable Energy Week, teachers will use *Genially* [29] platform so as to make all digital contents available to the students. *Genially* is an on-line tool for creating a wide range of interactive and visual contents, such as presentations, infographics, gamification and interactive images. Although *Genially* is a methodological resource and not a methodology itself, it can be framed into e-learning and active methodologies. The latter is the reason why it is included in this section. By using *Genially*, students will be involved with *Information and Communication Technologies* (ICT's) working thus their digital competence. Content management increases their handiness and availability through this type of online platform. Teachers can provide lecture notes in diverse formats (PDF, Word, Power Point, etc.) and complement them with a wide variety of didactic resources as educational videos or web links. Additionally, encouraging “learning to learn” competence is another reason to make use of *Genially* platform. Aiming to provide the reader with some resources that would be accessible during Renewable Energy Week, a *Genially* has been created [30]. The main page can be seen in Figure 2.

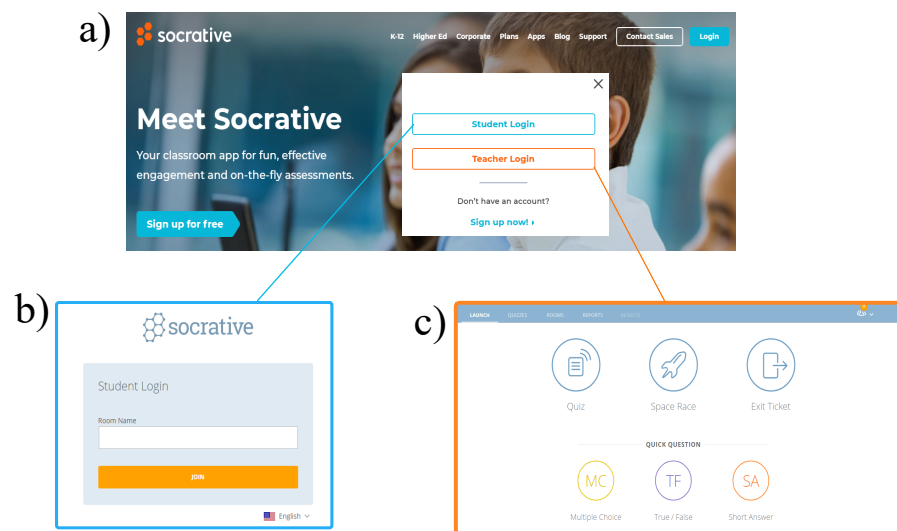


**Figure 2.** Main page of the material developed through Genially for Renewable Energy Week.

## 2.2. Evaluation: Socrative, Rubric and Question Sheets (“Scientific Sheets”)

One of the aims of the Renewable Energy Week sessions is to make the learners achieve meaningful knowledge about the essential concepts behind alternative electric energy sources. Therefore, evaluation process can not be seen by the students as an “additional difficulty”, but as a chance to demonstrate all the things they have learned. At the same time, the evaluation must serve the teachers to identify those contents in which the student could have had some difficulty. On this basis, the use of the following tools is proposed for the evaluation: *Socrative*, questions sheets and a rubric.

During Renewable Energy Week, it is intended to use *Socrative* as a diagnostic, formative and summative assessment tool (Figure 3). Aiming to take a look to the previous knowledge students have, a quiz with short questions related to those Physics, Chemistry and Technology concepts and linked to Renewable Energy Week will be launched at the beginning of the first session. At the end of each session, another short quiz will be launched, but this time, focused on the contents approached during the previous day activities (See supplementary material Figure S1).



**Figure 3.** Screenshots from *Socrative* application: (a) Home screen and access options (“Teacher” or “Student”), (b) “Room Name” request for the students and (c) Quiz options for the teacher [21].

As mentioned above, “scientific sheets” will be used in the evaluation process. These reports would be composed of about four or five short questions mainly related to the experiments scientific basis and extra information about renewable energies. These “scientific sheets” are available on supplementary material Figure S2.

Finally, rubrics are one of the most unbiased assessment tool, and it will be used to evaluate students performance (Figure 4) along Renewable Energy Week.

Since student opinion has further value for the organization and implementation of this educational proposal, students should additionally complete a satisfaction survey (supplementary material Figure S3).



Complete assessment: 70% rubric + 30% *Socrative*

Student: \_\_\_\_\_

Teacher: \_\_\_\_\_

*Renewable Energy Week: Evaluation Rubric*

Evaluation indicators (weighing)	Distinction	Good	Pass	Poor	Non acceptable
Collaborative Learning Individual work (30%)	Assumes his role, completes all the tasks assigned correctly in each session. <b>30 points</b>	Assumes his role, completes all the tasks assigned correctly in 3 or more sessions. <b>23 points</b>	Partially the pupil assumes his role, completing more than 50% of its tasks correctly in 3 or more sessions <b>15 points</b>	Partially the pupil assumes his role, but does not complete the tasks correctly along the sessions <b>8 points</b>	The pupil does not assume his role, not even try any task along the sessions. <b>3 points</b>
Collaborative Learning Cooperation with group (30%)	The student listens to their fellows, and shares with them his own tasks in every session. <b>30 points</b>	The student listens to their fellows, and shares with them his own tasks in 3 or more sessions. <b>23 points</b>	The student listens to their fellows, but DOES NOT explain his part in 2 or more sessions. <b>15 points</b>	The student listens to their fellows, but DOES NOT explain his part in ANY session. <b>8 points</b>	The student does not listen to their fellows and hinders his work. <b>3 points</b>
Attitude during sessions performance (20%)	The attitude has been respectful and there has been at least 1 contribution in each session. <b>20 points</b>	The attitude has been respectful and there has been at least 1 contribution in 2 or more sessions. <b>15 points</b>	The attitude has been respectful, but there were no contribution at any session. <b>10 points</b>	The attitude has been disruptive more than 2 times in each session. <b>5 points</b>	The attitude has been disruptive repeatedly, in each session. <b>2 points</b>
Scientific sheets (20%)	All the answers are correct. Clean and well presented without misspellings in any sheet. <b>20 points</b>	All the answers are correct. Clean and well presented and no more than 3 misspellings in each sheet. <b>15 points</b>	There is only 1 incorrect answer at 3 or less sheets. Clean and well presented and no more than 3 misspellings in each sheet. <b>10 points</b>	More than 2 incorrect answer in 1 sheet, or 1 incorrect answer in each sheet. Messy presentation, more than 3 misspellings in each sheet. <b>5 points</b>	There is no answer to the questions at 1 sheet, or some of the sheet has not been submitted. <b>2 points</b>

Figure 4. In-house created rubric for student activities assessment along *Renewable Energy Week*.

### 2.3. Curricular Contents

Contents included at the third year of compulsory secondary education that will be tackled during Renewable Energy Week are directly related to Physics and Chemistry and Technology subjects. Concretely, they are contained at the “Block 3: Movement and forces” and “Block 4: Energy” (Physics and Chemistry) as well as at “Block 4: Structures and mechanism: machines and systems” (Technology). All of them are explained in detail within Castile-Leon regional law “ORDEN EDU/362/2015” [9] previously mentioned.

### 2.4. Implementation and Development of the Educational Proposal

Renewable Energy Week is mainly composed of four sessions aimed to learn about the electric energy production through alternative energy sources. In a final fifth session, corresponding with the last day, all the projects are expected to be openly displayed along the building halls. To conclude that fifth session, and promoting social responsibility, an expert on the field of renewable energies or sustainability would be invited for giving a talk. This decision is motivated by the fact that a group of students included in Du et al. [19] project invited the director of a NGO (Non-governmental organization) to hold a guest lecture. The lecture had great success and the other groups showed a great deal of interest and felt inspired by it.

Sessions are framed into the secondary school centre Culture Week, in order to have more flexibility regarding timetables and classrooms and to fit it better into the Spanish secondary curriculum. Adaptation to other educational systems would be straightforward. All of them are designed as workshops at which the students must visualize experiments and set up some projects. The essence of Renewable Energy Week lies at its multidisciplinary character. At the end of each session students are intended to obtain a meaningful learning about particular concepts included at Physics and Chemistry curriculum, as well as Technology one.

The duration of each session is estimated in 80 min. In regard of classrooms and spaces, ideally the program would be carried out at the technology LAB, so the students would be provided with proper materials and tools (silicone gun, scissors, pliers, cardboard, wood, etc.) for building the projects. It will also be suitable that student groups were provided with a computer or a tablet with Internet access.

Physics and Chemistry as well as Technology departments are in charge of the Renewable Energy Week. It would be strongly recommended that two teachers were available for guiding the students properly. A summary of the implementation and organization of Renewable Energy Week is depicted at Table 1.

In regard of sessions themselves, four of them are focused on the acquisition of contents included at the curriculum and related, directly or indirectly, with the production of electric energy from alternative energy sources. In Table 2 a summary of the sessions is depicted. The final day an exposition with different stands will be placed along the Centre hallways, showing the most relevant highlights of Renewable Energy Week. Students must expose their projects, explaining how they work and showing its real life applications, especially those related with renewable energies. Pictures, diagrams, photos, schemes or any resource they consider should be used for supporting their expositions and enabling a clear understanding of difficult concepts.

**Table 1.** Organization of Renewable Energy Week.

Renewable Energy Week	
Implementation	During the Centre Culture Week
Intended for	Students enrolled in third year of Secondary School
Work methodology	Collaborative Learning Learning by discovery Experiments
Related subjects	Physics and Chemistry, Technology
Site	LAB

**Table 2.** Summary of the sessions framed at Renewable Energy Week.

Distribution of the Sessions			
Number of Sessions	5 Sessions		
Duration of the Sessions	80 min		
Session	Beginning	Half	Ending
S1	Introduction: Methodology of the sessions + How do renewable energies work?	Reviewing of previous knowledge: electric charge, electric current, magnetism, electromagnetism, Oersted experience. Experiments: potato battery, low-cost compass.	Crafting an electric engine with simple equipment
S2	Introduction and reviewing	Reviewing of previous knowledge: energy transformations, mechanical and electric energy. Relationship between electricity and magnetism. Generators and dynamos. Experiments: Dynamo (toy), paper propeller. Wind energy in the past.	Crafting a wind propeller with simple equipment

Table 2. Cont.

Distribution of the Sessions				
Number of Sessions				5 Sessions
Duration of the Sessions				80 min
Session	Beginning		Half	Ending
S3	Introduction and reviewing		Reviewing of previous knowledge: Ohm's law, current intensity, resistance and voltage magnitudes. Connection of resistors: in series and in parallel. Multimeters. Hydroelectric energy. World largest hydroelectric plants. Experiments: simple electric circuit implementation with <i>Protoboard</i> .	Crafting a small-scale hydroelectric system
S4	Introduction and reviewing		Solar energy: magnifying glass and how it focuses solar beams. Experiments: photovoltaic projects "Solar kit". Stirling engine.	Crafting a solar oven
S5	Project exposition		Talk about Renewable Energies	

#### 2.4.1. Session S1: Crafting an Electric Engine

##### S1.A Objectives

At this first session the methodology that will be followed while the Renewable Energy Week is introduced. These include: teamwork and roles, how to use *Socratic*, "scientific sheets" and rubrics for evaluation. In regard of theoretical contents, session S1 is intended to be a first approach between students and renewable energy fields, starting by knowing the different types of alternative energy sources. Also, students are expected to build their own electromagnetic induction engine.

##### S1.B Introduction

The main purpose of the introduction is to put the students into the context of the Renewable Energy Week. That includes explaining the motivation of the activity, presenting the timetables and introducing them the methodology (collaborative learning, roles within the work groups and experiments) as well as the evaluation process (*Socratic*, "scientific sheets" and rubric). Finally, some details about the final project exposition will be provided. This first introduction must not exceed 10 min long. The audience attention curve decay in a few minutes, specially when the audience is conformed by teenagers. According to Cuellar and López-Aparicio [31], half of audience attention is lost within the first 10 min. Thus, "twists" should be used along the exposition so as to try to recover listeners attention. During the introduction the students will be asked to make four people groups and to choose a name. The introduction will be supported by some slides (Figure 5). To conclude the introduction, the operation of the main renewable energies will be exposed to the pupils, in a concise and summarised manner (Figure 6).

##### S1.C Previous knowledge: Experiment with simple materials.

Before starting with the experiences, a short *Socratic* quiz will be performed by the students, as a diagnostic assessment (supplementary material Figure S1a). Thus, the teachers could adapt concepts and experiments according to the students' previous knowledge. The layout in groups pursues the correct visualization of the initial experiments. Likewise, in this moment students will be provided with the "scientific sheet" (similar to a short report), corresponding to this session (supplementary material Figure S2a) which must be completed by the "Scientist" along each session.

Then, a brief overview on electromagnetic phenomena will be done. Once this concepts are clarified, an scheme of a battery and how it works will be presented to the pupils, as well as its symbol to represent it in an electric circuit (Figure 7). Aiming to support the previous explanation, an experiment will be performed: “Potato battery” (Figure 8). The experiment is fully detailed in supplementary material Figure S4a).

In regard of magnetism, compass and magnets will be introduce to the students. An introductory and suitable question to catch their attention could be “Do you know the biggest magnet in the Earth?”. After a brief time, it should be explained that the Earth itself behaves as a giant magnet. Then, “Low cost compass” experiment supplementary material Figure S4b would be performed (Figure 9).

The last experiment is the basis of the most essential element that every power central needs, the electric generator. Oersted Experience (supplementary material Figure S4c) visually demonstrates the influence of electric current on magnets (Figure 10). From here, the teacher could deepen and explain the students there exist a relation between magnetism and electricity that leads to establish the concept of “electromagnetism”.

#### S1.D Project: Crafting an electromagnetic engine

This is the last part of the session. On the basis of the previous experiments and concepts covered before, the students are expected to be able to craft their own electric engine with simple materials. Although there are different configurations, the example taken is the one depicted in Figure 11. All the materials, scientific basis and the experimental method to perform this project are clearly detailed in supplementary material, Figure S4d.

In this moment, collaborative learning comes out, as well as the roles assigned. As mentioned in Section 2.1 (Methodology), the “Engineers” are in charge of the crafting itself (material selection, assembly, etc.). At the same time, the “Scientist” must answer the questions included at the “scientific sheet” (short report) given at the beginning of the session. The “Reporter” will search for relevant information about electromagnetic phenomena, as well as for real electric engines and its applications, among other information. A positive interdependence within the group is intended to be created.

For those students who have not completed the electric engine at session S1, they will be given an extra time at the beginning of session S2. This procedure will last along all the session.

**SUSTAINABLE DEVELOPMENT GOALS**

Sustainable Development Goals (SDG) are comprised of 17 goals proposed by the United Nations for achieving a better and more sustainable future for all.

You can find more about them by clicking here.

**7 AFFORDABLE AND CLEAN ENERGY**

**TIMETABLE AND GROUP ORGANIZATION**

Time	Mon	Tue	Wed	Thur	Fri
8:30 h – 9:50 h	3° A	3° B	3° C	3° D	Project exposition
9:55 h – 11:15 h	3° B	3° C	3° D	3° A	Project exposition
11:20 h – 12:40 h	3° C	3° D	3° A	3° B	Talk about RE
12:45 h – 14:05 h	3° D	3° A	3° B	3° C	

Session S1, Session S2, Session S3, Session S4

**WORK TEAMS**

4 PEOPLE GROUPS

CHOOSE A NAME

**THE ROLES:**

- 2 Engineers: Craft the project
- 1 Scientist: Write the "scientific sheet"
- 1 Reporter: Search for relevant information

Figure 5. Slides for introducing the students the organization of Renewable Energy Week.





Figure 6. Slides for explaining the different types of alternative energy sources.

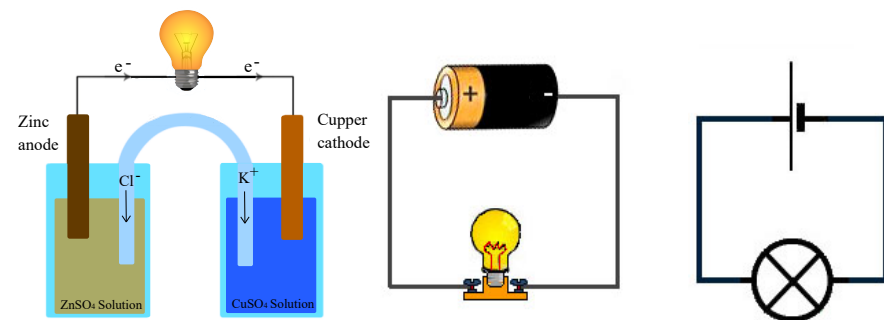


Figure 7. Scheme of how a battery works and its symbol within a simple electric circuit [32,33].

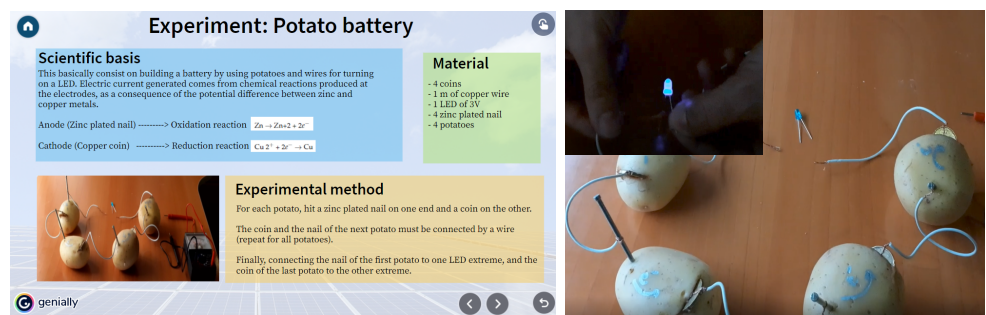
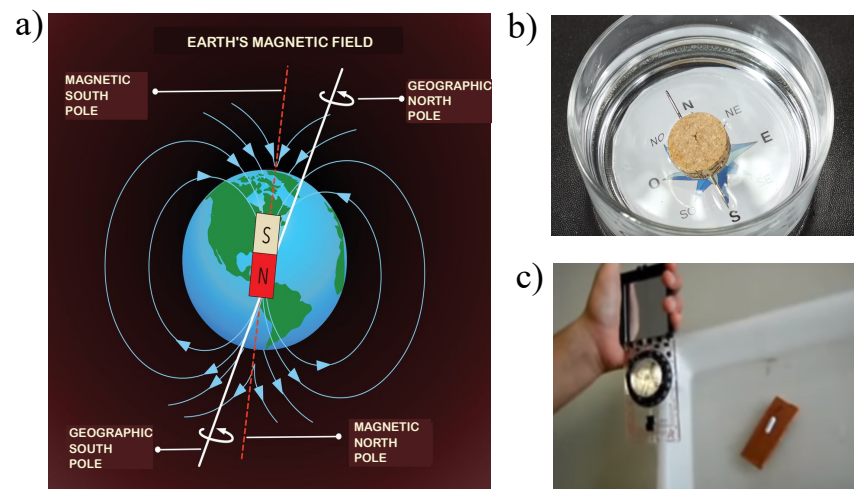
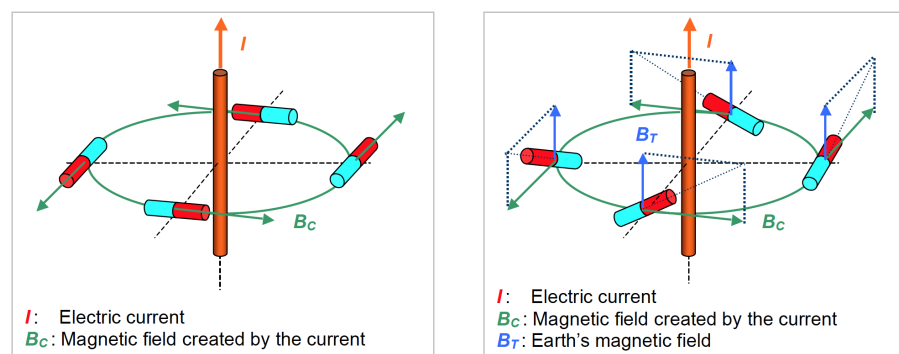


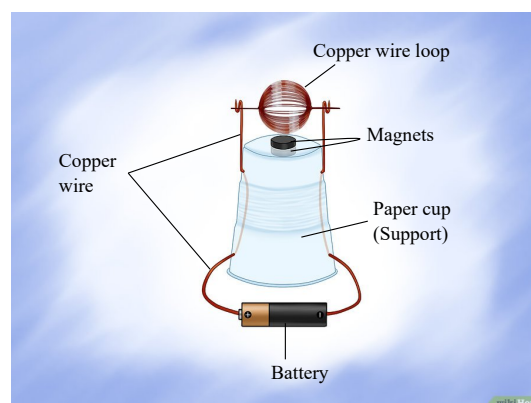
Figure 8. Instructions to perform the experiment and photos of the result.



**Figure 9.** (a) Scheme of Earth acting as a big scale magnet. (b) Low-cost compass experience. (c) Comparing low-cost compass experience with a commercial one.



**Figure 10.** Oersted Experience [34].



**Figure 11.** Scheme of an electromagnetic engine built with low-cost materials (adapted from [35]).

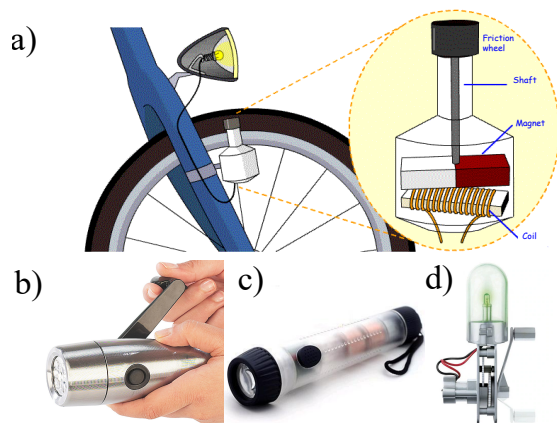
### 2.4.2. Session S2: The Force of Wind

#### S2.A Objectives

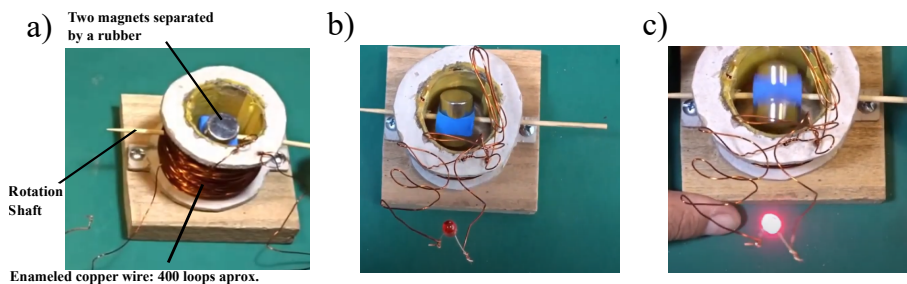
This second session is aimed to build a wind propeller with simple materials. The concept of electromagnetism will be resumed at the beginning. By visualizing some dynamos (Figure 12), the students are expected to discover the basis of the daily life electric machines. A hand-made dynamo (Figure 13) will be connected to a LED so as to demonstrate the electromagnetic induction. The students will be

ask to use their wind propellers as the source of energy for moving the dynamo and switching the LED on, at the end of the session.

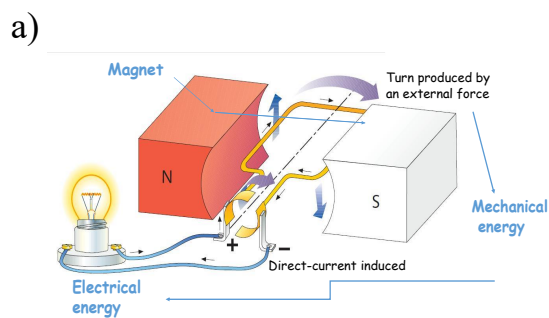
- S2.B Introduction and previous knowledge: Experiments with simple materials  
After completing the electric engine and the *Socratic* quiz, the concept of “electromagnetism” will be reviewed with the aim of introducing to the students the operation of dynamos. Once the electric engines have been checked, it would be interesting to ask the pupils the following question: “If electricity is able to create and influence the magnetism, would magnetism influence electric charges and currents?” This is the basis of the dynamos operation. Daily life examples can be mentioned, as the bicycle front light or flashlight dynamos and the teachers could also bring to the activity some specific material for science concepts learning (Figure 12d), like “Dynamo Torch”. Besides, the teachers could present a hand-made dynamo, crafted with simple materials, like the one presented in Figure 13. A brief summary about how to build it is depicted on supplementary material Figure S5a). The students will observe that when the shaft is rotating, an electric current is generated and it switches on the LED. A diagram to explain this can be shown in Figure 14a. Drawing on this, energetic transformations will be reminded to the pupils, outlining the transformation of mechanical energy into electricity. The latter is the basis of most power generation systems. Energy measurement units will be reviewed as well (Figure 14b).
- S2.C Project: Crafting a wind propeller with simple equipment  
At this moment, the session will be focused on wind energy. Firstly, the teachers should try to motivate the students by “challenging” them to move the hand-made dynamo shaft without using their hands. A wind propeller will be proposed for moving the dynamo and switching on the LED when it is driven by a hair dresser or similar. It must be said that a minimum wind speed is needed for switching the light, otherwise the magnetic field will not change fast enough (i.e., it became stable) to create the necessary electromotive force (EMF).  
Before starting the crafting, some relevant aspects about wind energy will be detailed. One or two slides for explaining that wind energy has been used since antique times (Figure 15a) may be employed. Besides, it must be explained that, in fact, wind is indirectly caused by solar radiation, which heats up the air creating convective currents. In order to illustrate this, the teacher could take to the activity a paper propeller (Figure 15b), supported by a slim stick. Four small candlelight will be lighted under the propeller. Thus, convection currents will make the air going up, moving the propeller (see supplementary material Figure S5b).  
Once the experiment is finished and students have no questions, they could proceed to build their wind propellers. The students are allowed to choose the design they consider. Some examples are depicted in Figure 16. The wind propellers must be able to be coupled to the hand-made dynamo, and it would be suitable to do this by means of pulleys or gears. These systems must be known by students since they are included in the curricular contents of Technology subject.  
Additionally, students will be provided with an specific interactive image, giving them more information about wind energy (Figure 17).  
Similarly to session S1, all the materials and scientific basis are detailed in supplementary material Figure S5c.



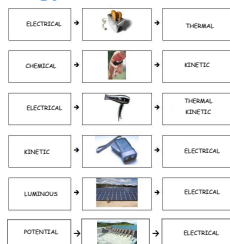
**Figure 12.** Different examples of dynamos. (a) Scheme of a dynamo in a bicycle, (b) Flashlight dynamo with crank, (c) Flashlight dynamo with shake switching and (d) Toy kit “Dynamo torch” (adapted from [36–39]).



**Figure 13.** Images from a hand-made dynamo, crafted with low-cost materials: (a) System overview, (b) System’s top view, (c) System working (Adapted from [40]).



**b) Energy transformations**



Energy is measured in Joules (J) within S.I

There is also other units, such as calories (cal) , or watt -hour (Wh)

$$1 \text{ cal} = 4,1868 \text{ J}$$

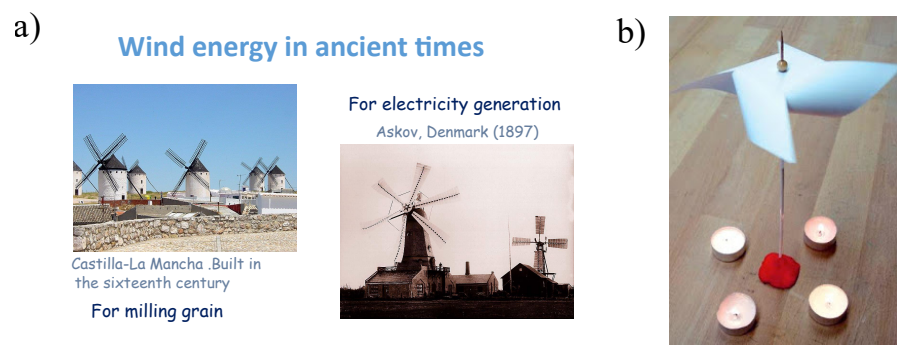
$$1 \text{ Wh} = 3,6 \cdot 10^3 \text{ J}$$

Electricity consumed at home is measured in kWh

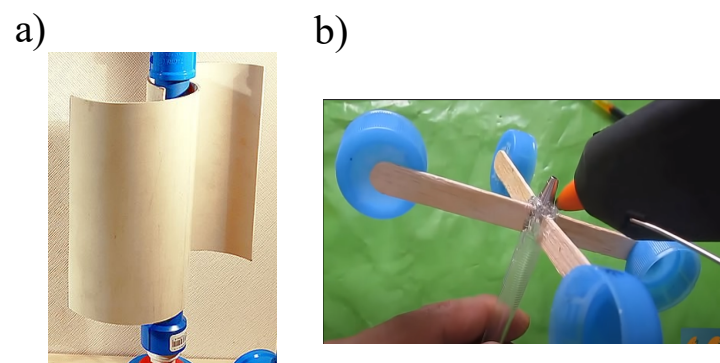
$$1 \text{ kWh} = 1000 \text{ Wh} = 3,6 \cdot 10^6 \text{ J}$$

**Figure 14.** Slides for explaining energy transformations: (a) Dynamo scientific basis, (b) Energy transformations. Examples and units (adapted from [41,42]).

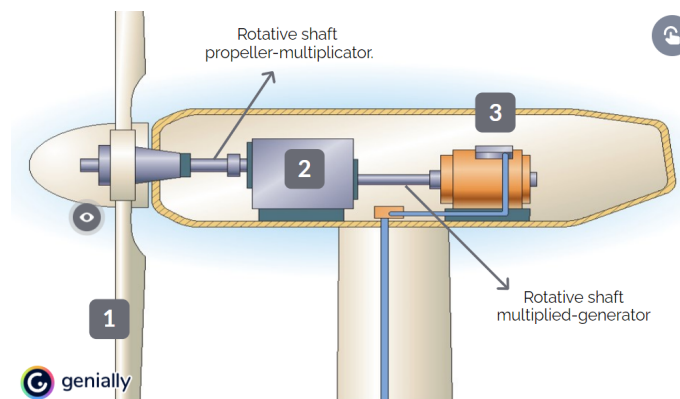




**Figure 15.** Proposed slides for introducing wind energy: (a) Wind energy in ancient times, (b) Wind propeller made of paper, powered by convective air currents (adapted from [43–45]).



**Figure 16.** Examples of propellers, made with low-cost material, for wind energy project: ((a) vertical configuration, (b) horizontal configuration [46,47]).



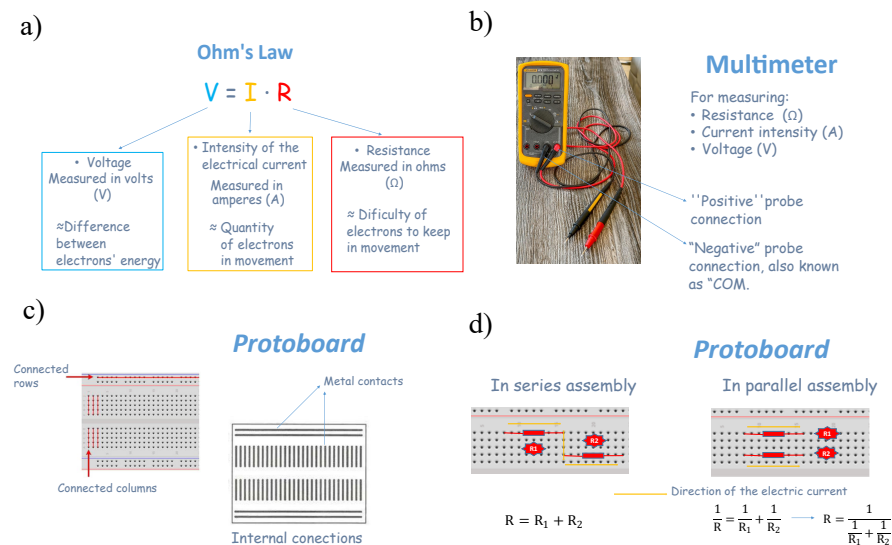
**Figure 17.** Interactive image related to wind energy (adapted from [48]).

### 2.4.3. Session S3: From Water to the Lamp

#### S3.A Objectives.

The essence of hydraulic electric power will be approached along this session. The students must craft a small scale waterwheel by using low-cost materials. The purpose of the waterwheel is to supply power to an electric engine that, at the same time, will switch on a LED. Thus, the performance of a hydraulic power plant, where the electricity is generated by the rotation of turbines, will be simulated. The turbine's movement is due to the potential energy storage at the dam. Furthermore, during this session, students will deepen into the assembling of simple electric circuits, measuring and associating the magnitudes of current intensity, potential difference and resistance.

**S3.B** Introduction and previous knowledge: Experiments with simple materials  
 At this stage of Renewable Energy Week, students have acquired wide knowledge about electricity and magnetism. Thus, taking a further step, pupils start to get involved with electric circuits, their elements and measuring instruments such a multimeter. This will allow the students to numerically connect electric current, potential difference and resistance. The teachers should present these contents on slides, focusing on multimeter connections. Also, Ohm's Law will be reminded, together with the expressions used for connection of resistors in series and in parallel (Figure 18a,b,d).



**Figure 18.** Proposed slides for explaining: (a) Ohm's law, (b) Multimeter and its connections, (c) Protoboard hidden connections and (d) Different assemblies for resistors. (Adapted from [49,50]).

After finishing the wind propeller and the *Socratic* questionnaire, each group will count with a Protoboard on their table (Figure 19), as well as wires, resistors, LED's and a power supply unit. The basis of a Protoboard is filled with metal contacts that allow the movement of electricity among them. These contacts are hidden inside, so a diagram must be shown to the students (Figure 18c). Then, they will be asked to assemble the association of resistors (330  $\Omega$  and 1k  $\Omega$ ) depicted below (Figure 20), adding an additional LED with the purpose of visualizing the difference between the circuits. The LED will vary its position at the circuit. First it will be placed after the two resistors in series (Figure 20a), and then it will be located after one of the resistor within the configuration in parallel (here, the LED intensity decay, Figure 20b). A power supply of 5 V is proposed to provide energy to the circuit. For each configuration the students must measure the magnitudes of current intensity, potential difference and electrical resistance, as well as verify Ohm's Law between points A-B and A'-B', as indicated in Figure 20.

**S3.C** Project: Crafting a small scale hydroelectric system  
 Finally, the session focuses on power hydroelectric plants. After reviewing and remembering the students how this power plant operates (Figure 21), each group will start crafting their own waterwheel. That implies, on one hand, the building of the waterwheel itself and, on the other hand, the assembly of a shaft that could transmit the movement of the waterwheel to a 12 V electrical generator. Then, with a water falling the waterwheel rotates, transmitting the movement (mechanical energy) to the electric generator (electrical energy). As a brief help for them, a *YouTube* video (Figure 21b) detailing the operation of an hydroelectric central is provided.

In Figure 22, some examples of waterwheels are presented. However, students could use other materials or crafting a different design (wider waterwheel, or recycling CD's out of use as support for the rotating blades). The scientific basis, material, and experimental method for this project is depicted in supplementary material Figure S6b.

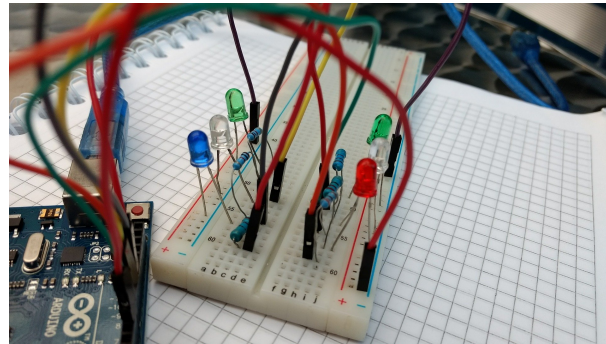


Figure 19. Picture of a Protoboard with Arduino, LED's and wires.

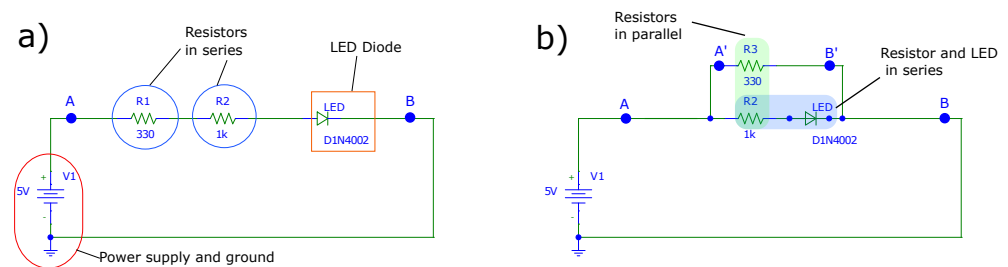


Figure 20. Scheme of the circuits students must assembly during session 3: (a) Series resistors assembly, (b) Parallel resistors assembly. In-home created by means of PSPICE-Schematics software [51].

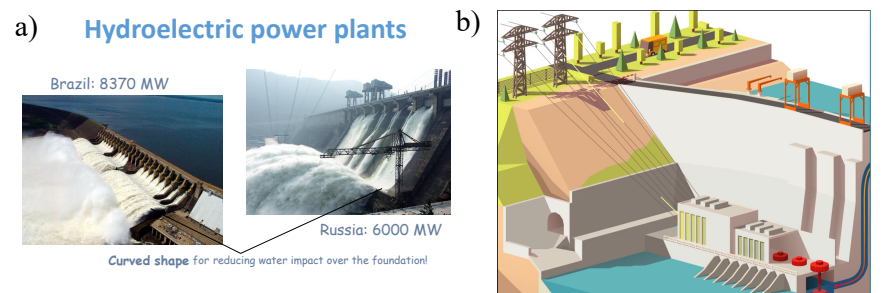


Figure 21. Hydroelectric power plants: (a) Real examples, (b) Video detailing the operation of hydroelectric power plants (adapted from [52,53]).

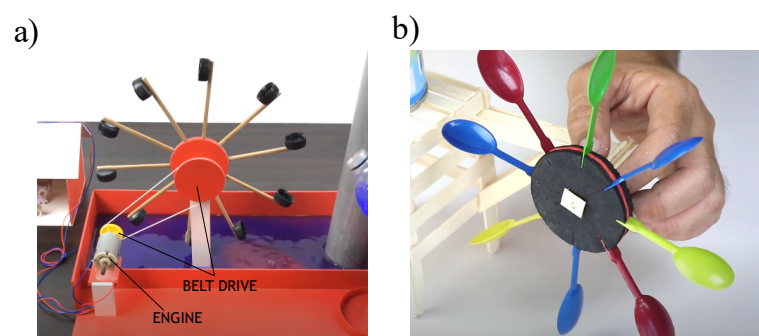


Figure 22. Waterwheels crafted with different low-cost materials (adapted from [54,55]).

#### 2.4.4. Session S4: Sun Provides Light and...Electricity!

##### S4.A Objectives

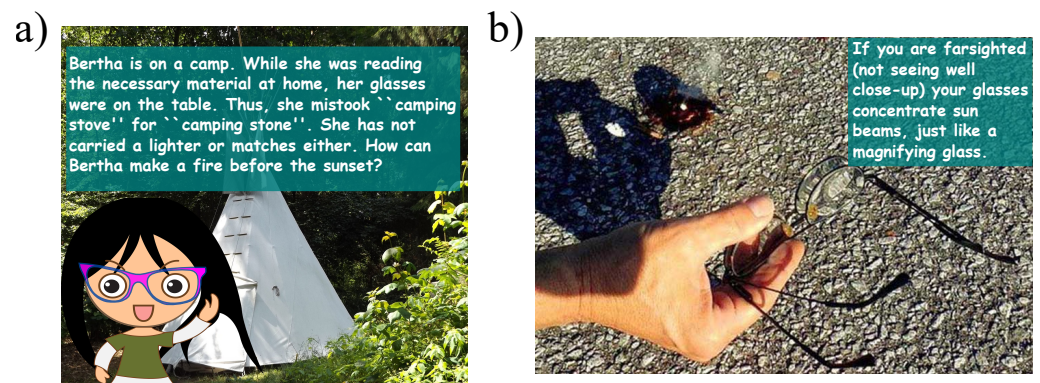
In this last session it will be deeply approached the electricity generation through solar energy. The difference between photovoltaic and thermosolar energy will be clarified. The teachers will make use of specific educational material aiming to show experiments about this type of renewable energy. Concretely, a photovoltaic "Solar kit" and a Stirling engine for simulating a thermosolar plant will be employed.

##### S4.B Introduction and previous knowledge: Experiments with simple materials

When compared to wind energy or hydroelectric energy, there exist more difficulties to find low-cost experiments that faithfully represent the operation of solar energy plants. This is due, firstly, to the solar light availability, and secondly, to the difficulty of creating a photovoltaic cell with low-cost materials or a solar collector connected to an electric generator. Aiming to overcome those problems, videos performing the experiments and recorded under good solar conditions could be used. Additionally, in experiences related to thermosolar energy, the heat provided by the Sun may be replaced by another source of heat, such as candles or a camping stove.

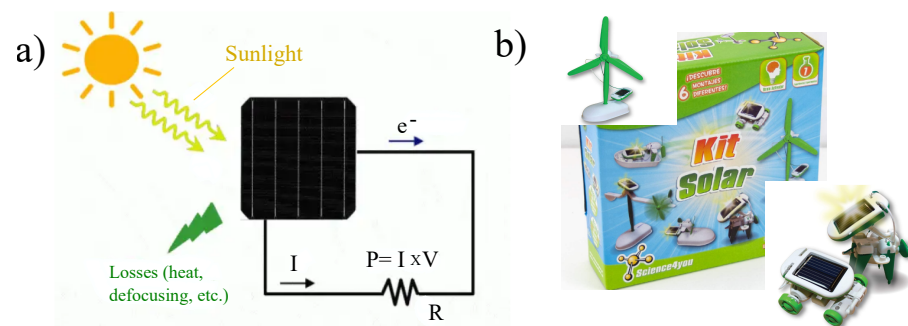
In this session, all the experiments will be performed by teachers, due to the difficulty of doing simple experiment about solar energy, as previously mentioned. With the purpose of promoting the students curiosity and introducing the session, a fiction situation will be presented Figure 23a. After a brief period of reflection, the teacher will reveal Figure 23b, and a demonstration *in situ* about how to set a fire with convex lens will be performed next to a window if solar irradiance makes it possible (supplementary material Figure S7a). On the contrary, a video showing the experiment should be played.

Then, the teachers will present the students a photovoltaic "Solar kit" (Figure 24) aiming to illustrate the photoelectric phenomena (supplementary material Figure S7b).



**Figure 23.** A brief story presented in pictures for promoting students curiosity: (a) Summary of the story and question raised, (b) Solution to the previously raised question [56].





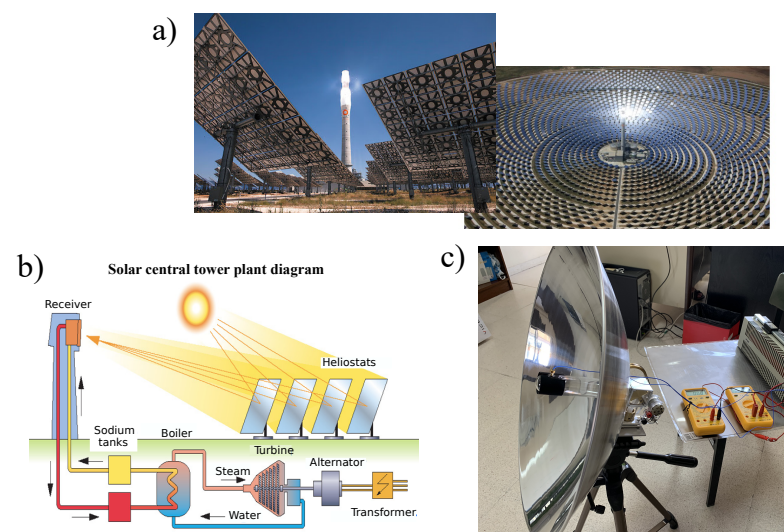
**Figure 24.** Photovoltaic energy: (a) Diagram of a photovoltaic cell operation, (b) Solar kit for the experience related to photovoltaic energy [57,58].

To conclude this part of the session, the performance of thermosolar plants will be detailed (Figure 25a,b) by means of a Stirling engine (Figure 25c) as a representative example (supplementary material Figure S7c). The engine would be propelled by a heat source (in real life thermosolar applications, the heat source would be the Sun). In case the Stirling engine could not being affordable, there exist some simulations of its operation [59].

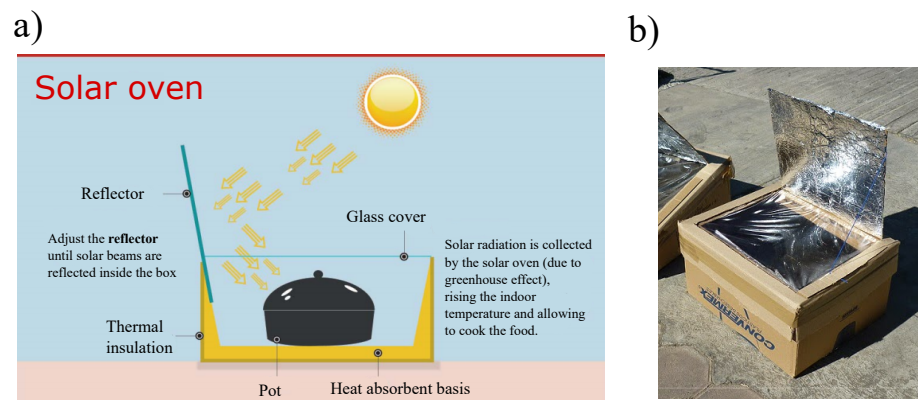
#### S4.C Project. Crafting a solar oven

To conclude the session, students will craft their own solar oven. Previously, teachers must briefly detail how the solar oven works and the reason of using specific material. In Figure 26a, the basis of the solar oven is depicted, and Figure 26b shows an example of what students must build. A detailed explanation is provided in supplementary material Figure S7d.

The last part of the session must be employed for answer a survey (supplementary material Figure S3), in which the students could evaluate their experience during the activities performed within the Renewable Energy Week. Then, aiming to present the projects to their fellows the next day, the exposition along the hallways should be arranged.



**Figure 25.** Thermosolar energy: (a) Gemasolar, a solar central tower plant, (b) Diagram of thermosolar plants operation, (c) Stirling engine coupled to a parabolic dish for producing power at small scale [48,60,61].



**Figure 26.** Solar oven: (a) Basis of solar oven performance, (b) Real example of a solar oven crafted with low-cost material [62,63].

### 3. Conclusions

A series of experiments and activities are collected in this work with the aim of working on the concepts related to renewable energies production. In order to present them in a way that can be useful to teachers, they have been organized into five sessions that could be given as a special activity named Renewable Energy Week. It considers Physics and Chemistry curricular contents as well as some concepts approached within Technology subject. This educational proposal is intended for third course of compulsory secondary school students (14–15 years old) although it could be implemented in other education stages and with a different structure. It has been developed on the basis of bibliography review, that generally claims for embedding sustainability into scholar curriculum through practical and real-life approaches. Similarly, the methodology developed was proved on the literature to be effective for students learning. It combines learning by discovery through experiments, which promotes critical thinking and a deeper understanding of concepts. Collaborative learning is also involved, through role assignments, so as to create a positive interdependence among the students.

Innovative techniques for evaluation have also been applied, such as: rubric, *Socratic* quizzes and a brief report called “scientific sheet”. They are intended to serve the teachers for assessing the students from a global perspective, attending not only to the concepts itself, but also students procedures and attitude.

The first four sessions include a brief review of concepts related with physical phenomena, low-cost experiments and building of a project. Each session regards to a different type of renewable energy (wind energy, hydroelectric energy, and solar energy), except session S1, which serves as an introduction to the others. Session S5 includes a project exposition along the hallways of the Centre and a talk about renewable energy, held by some expert on the field.

Renewable Energy Week is expected to enhance the interest students have on scientific subjects, as well as the concern about sustainable development, environment, and alternative energy sources. At the same time it intends to make easier teachers’ task when planning activities trying to enhance students awareness about sustainability, renewable energies, and SDGs.

**Supplementary Materials:** The following are Available online: <https://www.mdpi.com/article/10.3390/su132212904/s1>, Figure S1: *Socratic* quizzes for Renewable Energy Week, Figure S2: Scientific sheets designed for Renewable Energy Week, Figure S3: Session S4. Final survey about Renewable Energy Week, Figure S4: Session S1 Scientific basis, materials and experimental method, Figure S5: Session S2. Scientific basis, materials and experimental method, Figure S6: Session S3. Scientific basis, materials and experimental method, Figure S7: Session S4. Scientific basis, materials and experimental method.

**Author Contributions:** Conceptualization, J.G.-F. and M.J.S.; methodology, A.M.; investigation, J.G.-F. and R.P.M.; writing—original draft preparation, J.G.-F.; writing—review and editing, M.J.S., R.P.M., A.M.; supervision, J.M.M.R. All authors have read and agreed to the published version of the manuscript.

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### Abbreviation

The following abbreviations are used in this manuscript:

SDG Sustainable Development Goals

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