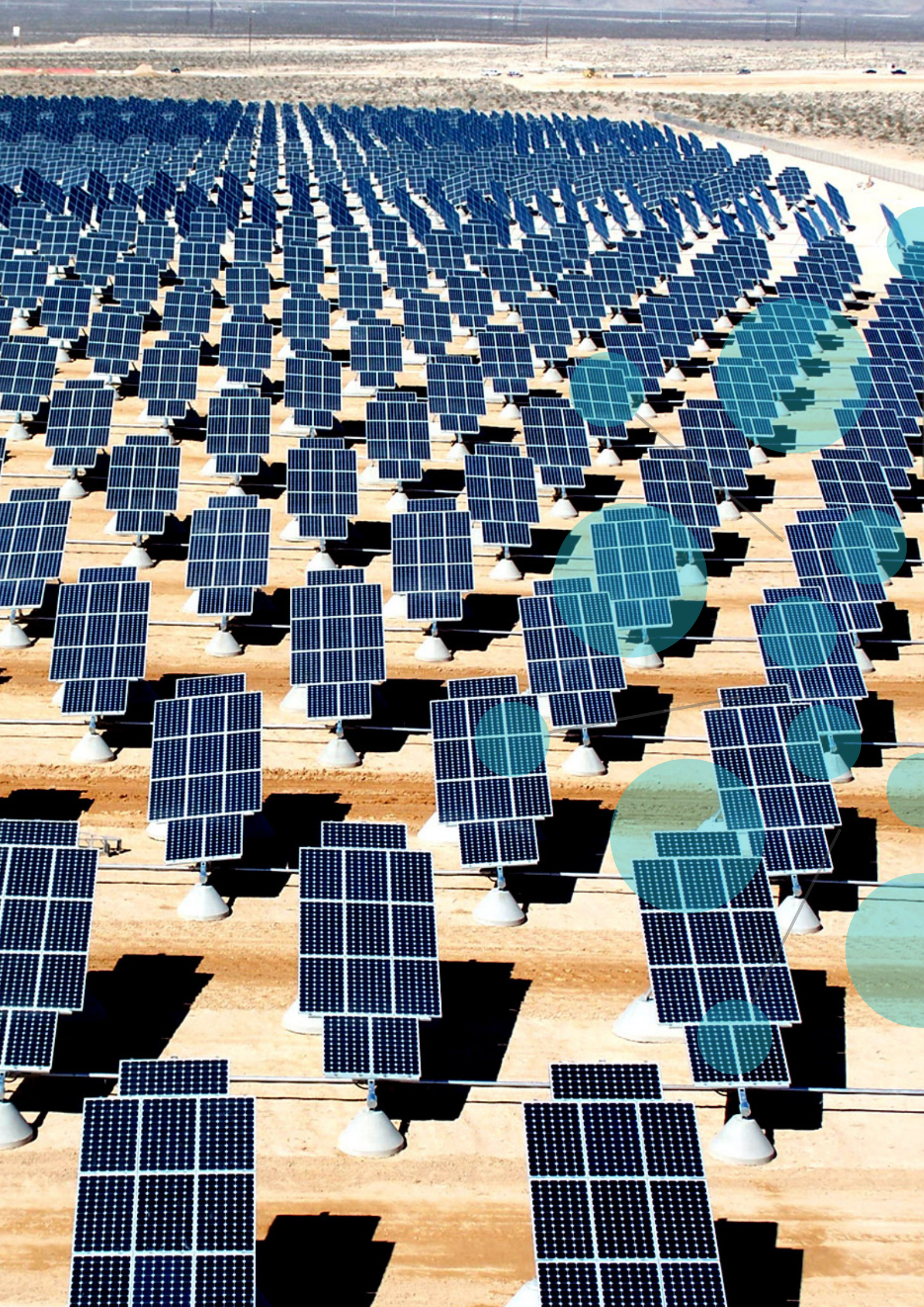
irresistible

Responsible Research and Innovation (RRI)

Applications of nanomaterials in solar energy systems

6

Universitatea Valahia din Targoviste



Applications of nanomaterials in solar energy systems

An educational module for sciences lessons for primary, lower and upper secondary school levels, developed by a researcher and a Physics teacher from Târgovişte, Romania.

Developed within the framework of the European project -IRRESISTIBLE – Engaging the Young with Responsible -Research and Innovation – www.irresistible–project.eu

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1 Overview 6

2 Educational scenario 16

3 Teacher guide 18

Engage. Explore 20

Explain. Elaborate 22

Expose. Evaluate 26

Evaluation 28

4 Sources 30

5 Colophon 32

1

Overview

Applications of nanomaterials in solar energy systems

The sun, inexhaustible source of energy, helps keep the planet's temperature and maintain the life on the earth. Daily, our life is influenced by the energy use. When we prepare the food, go to the school, use the computer or drive the car, we consume energy. All these actions of ours produce CO2 and other pollutant emissions.

Using the solar energy as renewable energy source (green energy) and with the small changes in our behaviour we can contribute to a major reduction of the pollutant emissions considering the following aspects:

- *the fossil energy sources are not infinite; the natural gas and the oil are insufficient so, the battle for these sources becomes more severe;*
- *the carbon dioxide emitted through the burn of the fossil energy sources is the main cause of the global temperature increase, with huge influence on the future living conditions;*
- *since the beginning of the industrial development the carbon dioxide concentration in the atmosphere has increased by 30%, causing global warming with 0,4 - 0,8°C;*
- *the increasing of the temperature led to warming seas and oceans thus causing the melting glaciers. As a result, the sea levels the rose and flooded the coastlines. In addition, the summers are hotter and drier and the winters have more rainfalls. The extreme weather events - such as hurricanes, storms, etc. have become stronger and more frequent and the deserts are expanding.*
- *the sun - a huge reactor of the nuclear fusion - there will be a few billion years; the energy radiated by the sun on the continents (219.000.000.000 million kWh) each year is 2,500 times the annual energy global consumption.*

Overview

Grade/Educational level		primary-secondary-high school
Domain		Nanomaterials
Theme / themes of non-formal activity:		**Applications of nanomaterials in energy production**
Educational objectives		1. To identify the characteristics of solar energy conversion systems; 2. To understand the difference between solar thermal panels and photovoltaic panels; 3. To analyze the physical phenomena that allow the conversion of solar energy into other forms of energy (electricity, heat); 4. To argue the advantages and disadvantages of using solar energy systems; 5. To apply the knowledge gained in the determination of the specific parameters for the photovoltaic installations: maximum power, energy yield, etc;
Required preconditions		- knowledge of the solar energy, its dependence of the geographical area and season; - knowledge regarding the energy production and their effects on the environment.
Procedural resources (teaching strategy)	Teaching-methods and procedures	Exposure, conversation, explanation, demonstration
	Educational means	Photovoltaic panels, solar thermal panels, educational kits of solar energy domain, video projector
	Forms of activity organization	Debates and experiments carried out in groups, front presentation of the group conclusions
Estimated time		3-4 hours

figure 1.1

Scientific and Technological Institute of Multidisciplinary Research, Valahia University of Târgoviște, Targoviste, Romania

Sections

1	Scenario of the non formal activity	The event will takes place at the Scientific and Technological Institute of the Multidisciplinary Research (ICSTM) from the VALAHIA University of Targoviste. The 210 participating students will be divided into groups of 30 students; each group being allocated one hour for the activities proposed under the theme. The 7 groups will have access to the ICSTM building as a planning hour, between 9:00 – 15:00. Each of these groups will participate in a visit lasting approximately 20 minutes in ICSTM, during which students will have the opportunity to see the solar energy laboratories. Further, for a period of about 20 minutes, will be performed outdoor activities with demonstration experiments dedicated to solar energy conversion. Finally, the students will participate to a debate organized into the ICSTM Amphitheatre with the following topics: **1) Is it opportune to make investment in solar energy conversion equipment?** Based on the knowledge gained, students will argue their opinions and their decisions on the following: • intended use of solar energy products (for individual housing, group housing for a village), • financial factors, • profitability, • environmental quality, • architectural aspect. 2) **How do you evaluate the role of research in the field of solar energy conversion systems? What problems would be solved in this domain?** The duration of this activity will be about 20 minutes.

2	Proposed guide	The activities performed in the framework of ICSTM will allow to each student to learn the basic information needed to understand the utility of solar energy installations by visualizing the equipment, from the discussing with researchers and participating in simple experiments and finally, through exchanging of ideas in the final debate.
3	**Evaluation**	Will be assessed the following aspects: • the interest in the topics addressed; • the involvement in the experiments; • the communication with the colleagues and the experts in solar energy; • the ability to support a decision on the use of solar energy conversion equipment; Also, students will complete a form.

The activities uniqueness of the IRRESISTIBLE Module lies in the experiences addressing of non-formal learning dedicated to the Sciences in a format witch involving a 6-step model (6E - see Annex no. 3). To ensure the achievement of the proposed objectives, it starts from a real-life situation, developing further the connection between it and the specific contents of the science domain, so as to meet the needs of the students learning.

The activities uniqueness of the IRRESISTIBLE Module is ensured also by:

- motivational title - facing to a problem cropped in reality, likely to generate a socio-scientific approach;
- centred teaching subtasks on the IBSE and RRI - to facilitate the assimilation of scientific knowledge by students;
- student-centred approach and oriented towards solving a problematic situation, providing training / skills development of learners, according to the needs of society and the principles of responsible citizenship;
- appropriate use of scientific knowledge, skills, generally in the context of an investigative approach centred on the 6E model;
- use the Web 2.0 technologies in investigative approach (exploratory and communication and presentation of the results.

Short Theoretical Background

Solar thermal conversion

In a solar thermal solar installation, the solar radiation heats the heating fluid (water or air)

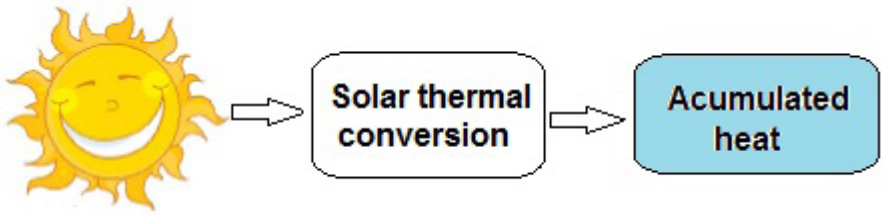


figure 1.2

The scheme of the solar thermal conversion

which is circulated through a solar thermal collector, with the utilities of domestic warm water production or the conditioning of the buildings indoor air.

The explanation of the trial in the photovoltaic solar cell conversion

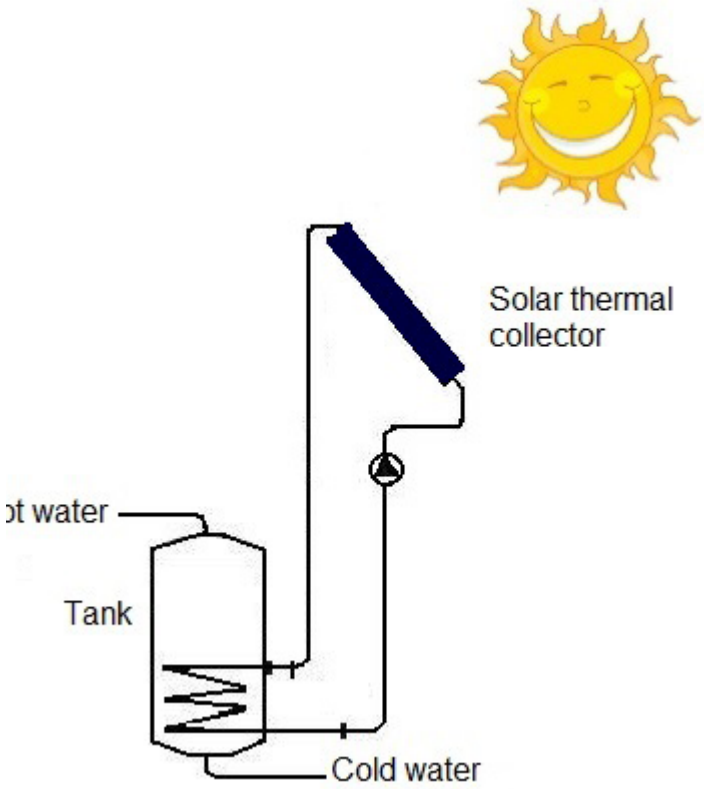


figure 1.3

Schematic representation of the solar thermal installation

The operation of photovoltaic cells is achieved due to the semiconductor property of directly converting the solar energy into electricity. Through the photovoltaic effect, the energy of the solar radiation (photon energy) is converted directly into electricity.
One of semiconductor devices in which this effect can be highlighted is the p-n junction type.

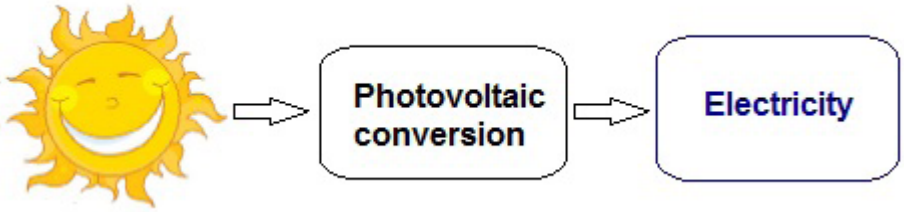


figure 1.4
The photovoltaic conversion

In the case of the p-n junction of the PV cell is necessary that the energy of the incident photon, hv, to be greater than or equal to the width Eg of the semiconductor band gap. In this case, by the action of the photons with hv ≥ Eg on one or other of the regions which forming the p-n junction, or even on the both regions simultaneously, are photo generated the majority carriers, n-type or p- type.
Near the junction occurs the majority charge carriers diffusion from one region to the other, where they are a minority. Thus, in the vicinity of the junction is determined a region with the space charge, positive in the n region and negative in the p region. The electric field created Ei (internal field) is oriented from n- type semiconductor to the p-type semiconductor and causes a potential barrier Uo.
The energy produced by the solar photovoltaic systems mainly contributed to the rural development and allowed the electrical power supply of the remote areas or inaccessible to the conventional power deployments with the following advantages:

- better light quality, emissions and noise reduction produced in the case of the diesel electric generators;
- development of education through the access on telecommunications and internet in the remote areas;
- improving the health through the drinking water (water pumps driven by electrical photovoltaic systems), proper storage of vaccines and drugs;
- agricultural areas irrigation (water pumps);
- power stations in orbital stations around the Earth.

As a key element of a photovoltaic installation, the photovoltaic cell (PV cell) is now used for buildings construction and renovation. Being integrated in the structure of the buildings, the solar cells are actively an element of producing electricity and passively being an architectural and constructive element of the building, replacing traditional building elements such as brick, concrete, stone, etc.

The presentation of the conventional solar cell structure

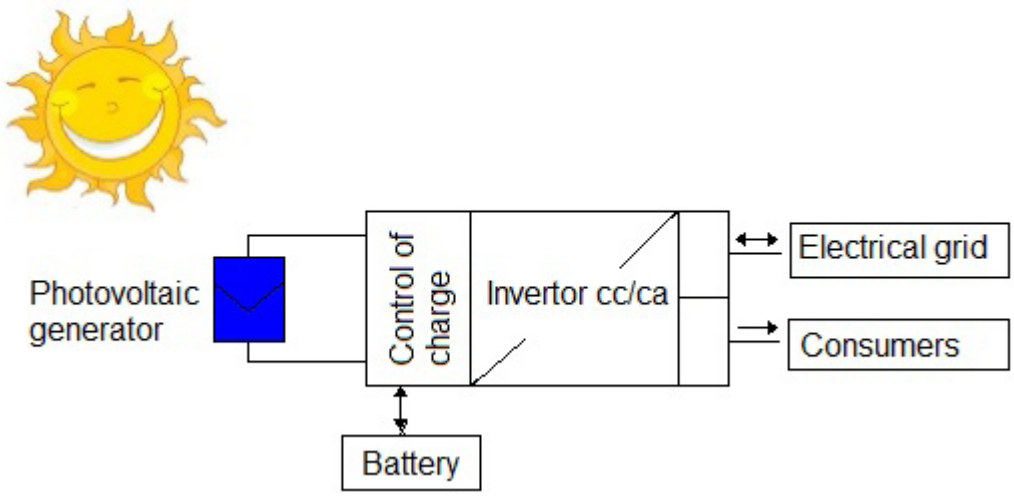


figure 1.5
Schematic representation of the photovoltaic system

Conventionally, the photovoltaic cell is made of an n-p type semiconductor, having silicon as a base material or a combination of silicon with various inorganic or organic materials resulting in the so-called hybrid solar cells.

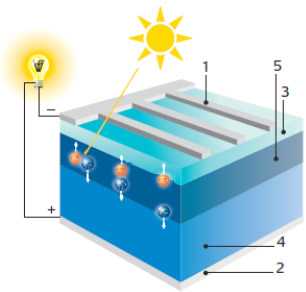


figure 1.6
Schematic representation of a photovoltaic cell

1 - negative grid electrode
2 - positive electrode
3 - n-type layer
4 - p-type layer
5 - junction where diffusion occurs for majority charge carriers from one region to another

The most common materials used in the construction of solar cells are: silicon, gallium arsenide (GaAs), cadmium sulphide (CdS), cadmium telluride (CdTe), germanium, indium phosphate (InP), aluminium antimoniura (AlSb) and gallium phosphate (GaP).

The most important feature of a solar cell is the efficiency expressed as efficiency of conversion defined as the ratio of the electrical power P_M in peak conditions (sunlight = 1000 W/m^2, ambient temperature t = 20°C, air mass AM = 1 5) and the radiant incident power.

The increasing of the solar cells efficiency involves the use of the semiconductor with the band gap energy levels for effective use of the full spectrum of solar radiation, appropriate technologies for electrical contacts scale and antireflective coatings (silicon dioxide film) that reduce reflection losses. The disadvantages of such a system conversion are high cost and difficulty of storing large amounts of electricity.

The presentation of the three solar cell generations, from the silicon wafers to the solar cells with nanoparticles.

Depending on the technology of fabrication, solar cells are classified as follows: (1) the first generation - crystalline silicon (c-Si); (2) the second generation - thin film cells; (3) he third generation – concentrator cells and hybrid nanoparticles cells.

The crystalline silicon cells

More than 90% of the solar cells are the cell of silicon. Silicon is found in a fairly large proportion of about 27.7% on the Earth's surface, in second place after oxygen, is found in the constitution of rocks, sand, clays and soils in combination with oxygen as silicon dioxide or oxygen and other elements in the form of silicates. The crystalline structure as a diamond, silicon is the fourteenth periodic system element being in the group IV A, with germanium, carbon, tin and lead.

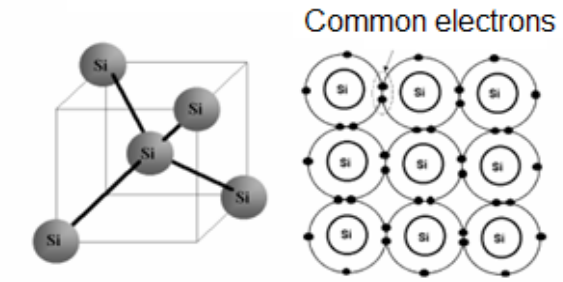


figure 1.7
Schematic representation of a single crystal of silicon

For the manufacture of the silicon solar cells is required to obtain maximum silicon purity in a process for the extraction of oxygen from the quartz sand carried out at a temperature of 1800ºC, in combination with coal or wood.

After obtaining pure solid silicon with dark gray and polycrystalline structure, it is poured into ingots which are cutting in the silicon wafers with a thickness of 0.3 mm, on the surface of which are made n-type or p- type diffusions to achieve a n-p semiconductor junction.

For most applications the solar cells are mounted in a module (36 of solar cells are connected in series to a voltage of 12V). Solar module support is to customer adapted and can be made of aluminium alloy, galvanized steel or treated wood. The highest conversion efficiency of solar cell silicon, 24% was obtained in the laboratory.

In general, silicon cells have efficiencies offered between: 20% for monocrystalline silicon; 16% for polycrystalline silicon.

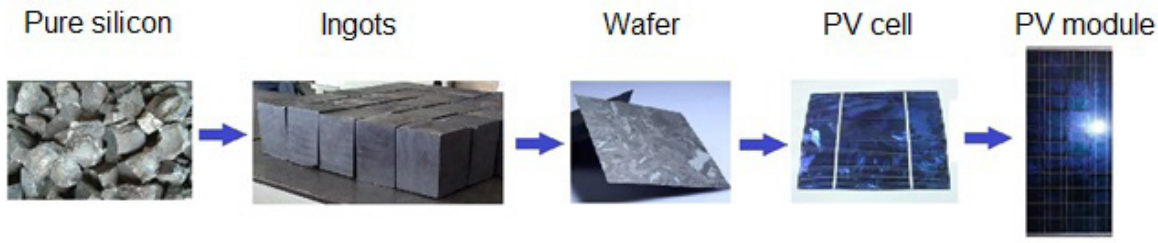


figure 1.8
Steps of solar cell manufacturing

Educational scenario

Steps of non-formal activity/ time management	Educational objectives	Proposed activities	Non-formal Learning activities
1. Engage	Understanding and explanation of some physical phenomena, of some technologically processes and using of some technical products encountered in daily life	Presentation of some solar energy systems; Presentation of the Energy-Environment Research Department laboratory;	Observing the physical and functional characteristics of solar energy conversion equipment
2. Explore	Skills training of achievement of some simple experiments	Organizing of simple experiments	Observation of highlighted phenomena, participation in experiments
3. Explain	Understanding of the highlighted physical phenomena	Explaining the operation of the used devices	Student-researcher communication
4. Elaborate	Applying new knowledge in making a decision on whether to use solar energy conversion systems	Launch questions deliberation	Listening and understanding the requirements formulated by questions
5. Disseminate / Share / Present / Expose	Presentation by the students in the group's they own views on the use of solar energy conversion systems and the opinion on the importance of research from this field	Listen to the student responses, requests additional information or supplemented, if is necessary	Presentation by students of their own opinions on the opportunity to invest in solar energy conversion systems
6. Evaluate	Assessment of learning performances recorded by students	Share evaluation form	Complete the evaluation form

The results of non-formal learning	Non-formal activity strategy			Evaluation
	Teaching methods and procedures	Means of education	Forms of organisation	
Understanding the types of solar installations	Conversation, explanation	Solar installations	Frontal	Oral assessment
Skills training of analysis and synthesis	Demonstration	Photovoltaic panels, solar panels, measuring instruments	Experiments obtained on groups of students	Evaluation of experimental skills
Understanding the installations operation and of the physical phenomena production	Experiment	Photovoltaic panels, solar thermal collectors measuring instruments, charts, posters	Group discussion	Oral evaluation of the understanding level for the new knowledge
Develop individual response	Conversation	Video projector	Frontal	Evaluation questions raised interest
Communication of diverse ideas, opinions on the subject under discussion, identifying solutions	Conversation		Frontal discussions	Evaluation of the communications skills by using of the specifically terms for the experiments and phenomena
Written expression of students' own opinions regarding the questions from the form	Evaluation by written questionnaire	Print questionnaire	Individual	Written review

3

Teacher guide

Teacher guide

This activity promotes the scientifically education to the students through the non formal education strategies. In the framework of the activity, are addressed research and responsible innovation problems (RRI), in the context of the proposed themes (see Annex. 2). In this sense, the students (with the instructors) will create the specific exhibits, in the context of the themes of the solar energy and the RRI principles. These exhibits will be presented in science centres, museums etc...

1. Engage. Explore

Moment 1: Visit the laboratory of Energy Environment Research Department

The researcher shall present to the students the activity and achievements of the department; are also presented tools and facilities used in the current research (figure 3.1).

During the visit, the researcher provides a climate of communication with students, the purpose of responding to their questions and stimulates students' interest in research activities in the department.

figure 3.1

Solar instruments for measure the efficiency on the nano structure of the PV cells (100 – 1100nm)

Moment 2: Visit the solar systems integrated on the building terrace of ICSTM

The researcher shall give to the students the information's regarding the components of the solar energy systems presented in figures 3 - a, b, c, operating parameters (maximum power, efficiency, the voltage across the panel, the average electricity produced in the year, etc.), costs of purchase, installation and maintenance.

At the end of the visit, the researcher informs students that they will be asked to answer the following questions:

1) Is it opportune to use a solar energy system?

There are considered the following issues: solar energy produced destination (for individual housing, group housing for a village), financial, environmental quality, profitability, architectural aspects;

a) PV system

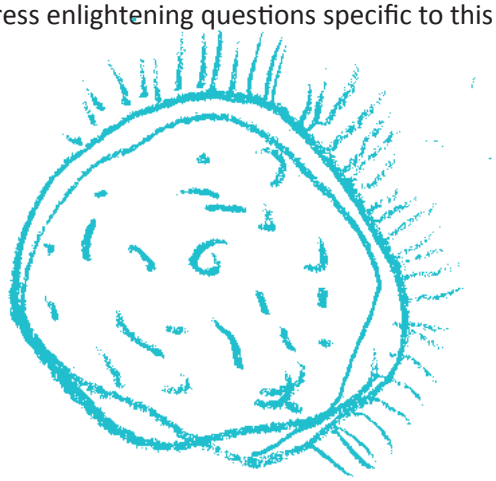
a) Solar radiation sensors

figure 3.2
Solar systems on the ICSTM terrace

c) Solar thermal system for the hot water supply

2) How do you evaluate the role of research in the field of solar energy conversion systems? What problems do you think should be addressed in this field?

Students will be asked to address enlightening questions specific to this stage of the activity.



2. Explain. Elaborate

Moment: The participation on the demonstration experiments which are study objectives the components of solar energy conversion equipment

The 30 students will be divided into the 4 groups; they will participate on the solar experiments with the support of the assemblies and devices shown in next figures (the images were performed on the ICSTM Laboratory - Building integration of renewable energy systems. Autonomous systems and energy management - Laboratory Responsible – PhD. Researcher Gabriela Mantescu).

figure 3.3
Solar thermal elements for a hybrid photovoltaic/ thermal panel (Image from the Laboratory: Building integration of renewable energy systems. Autonomous systems and energy management - ICSTM)

figure 3.4
Hybrid photovoltaic/ thermal panel (Image from the Laboratory: Building integration of renewable energy systems. Autonomous systems and energy management - ICSTM)

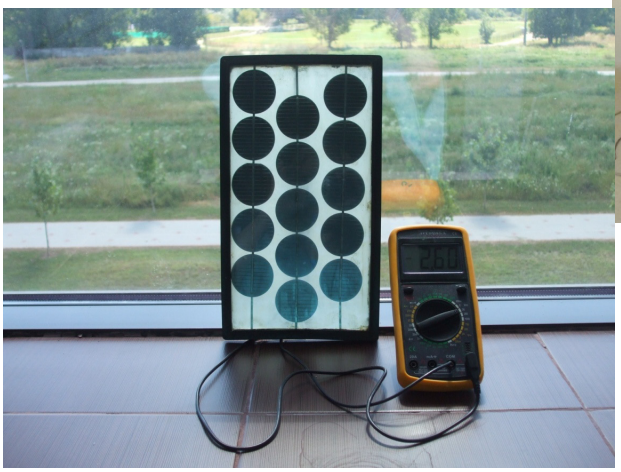


figure 3.5
Photovoltaic (PV) panel with single crystal silicon solar cells – the firsts PV panels made in Romania (years: 1983 -1985);

figure 3.6
PV panel

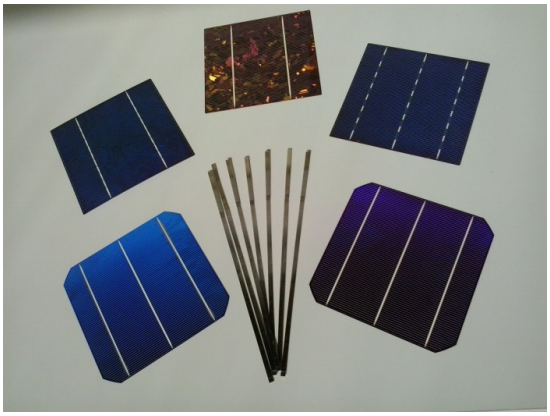
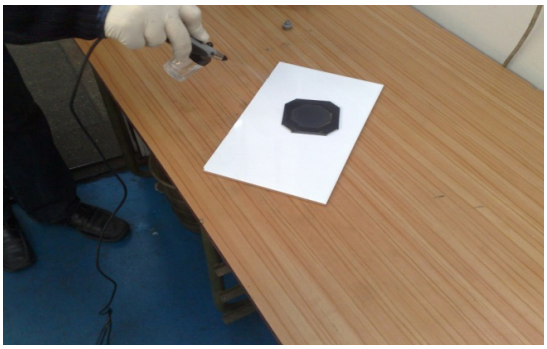


figure 3.7
Polycrystalline silicon cells

(PV ALTIUS, made in Romania, 2014)
(Image from the Laboratory: Building integration of renewable energy systems. Autonomous systems and energy management - ICSTM)

figure 3.8
CdS/CTe photovoltaic cell
(CdTe=1=10m, CdS= 100-300nm),
(Image from the institute ICPE-CA – Bucharest)



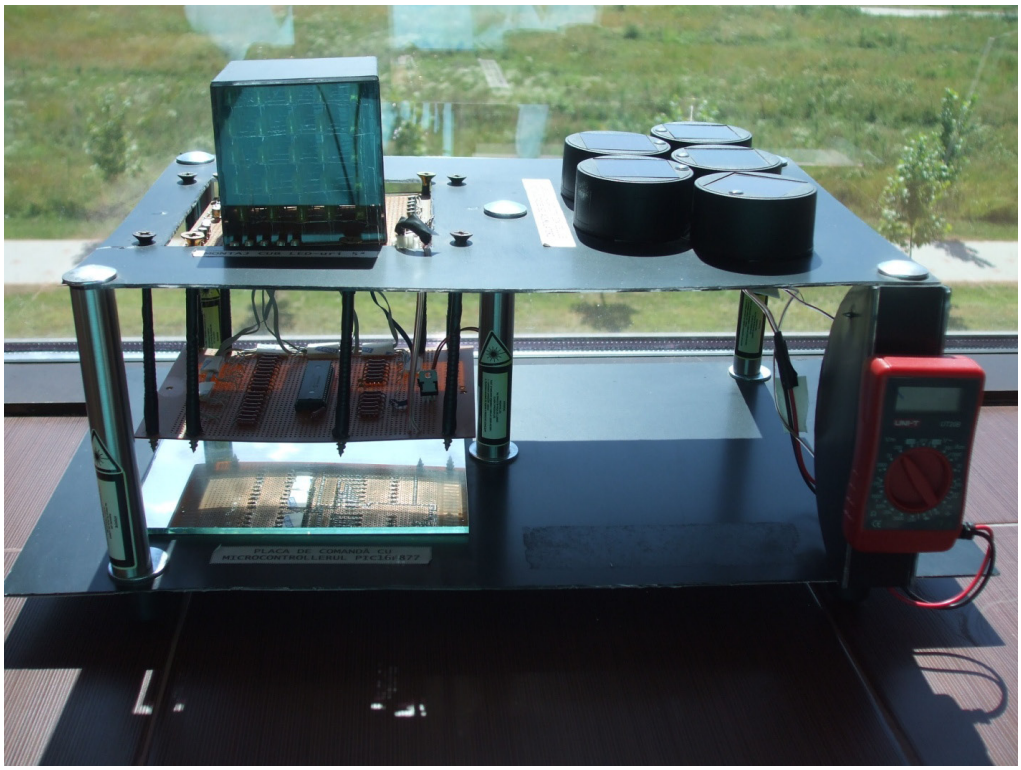


figure 3.9
Photovoltaic application

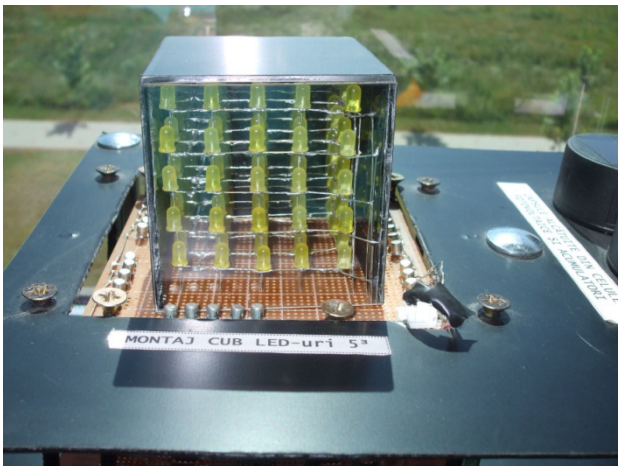


figure 3.10
LEDs
(Image from the Laboratory: Building integration of renewable energy systems. Autonomous systems and energy management - ICSTM)

figure 3.11
PV cells with battery
(Image from the Laboratory: Building integration of renewable energy systems. Autonomous systems and energy management - ICSTM)

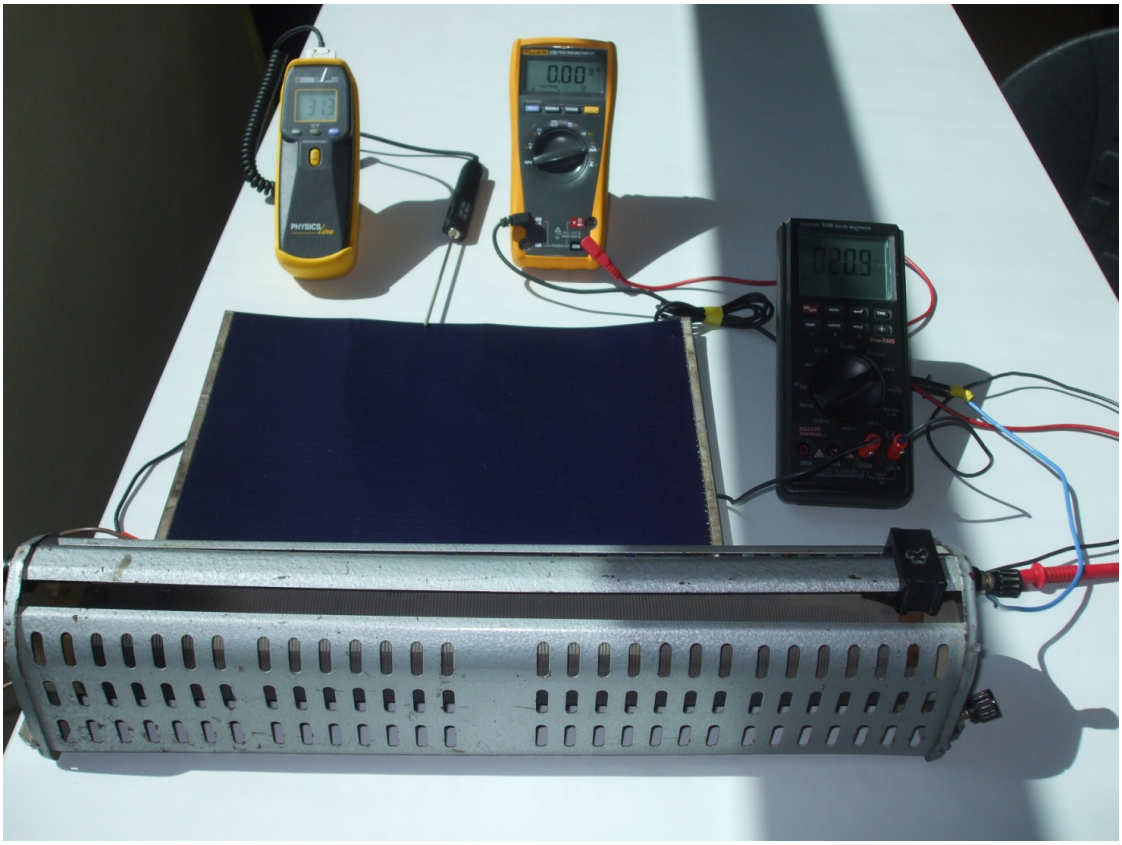


figure 3.12

Determination of I - V (current c.c. – voltage c.c.) curve for a photovoltaic flexible panel

In each experiment will be highlighted the physical phenomena underlying the conversion of solar energy into the electricity or the heat. Students can observe the operating principles, storages possibilities of the electricity, can measure electrical current and voltages and will calculate the output power.

The researchers which will conduct the experiments will highlight the main physical features, the physical parameters and the usefulness of these applications, asking students to express their opinion about the solar energy applications.

3. Expose. Evaluate

Moment: The student's exposure of the personal views and impressions regarding the activities carried out in this project

Will be launched the following deliberation questions:

1. Is it opportune to invest in solar energy conversion equipments?

Based on the acquired knowledge's, the students will argue their decisions taking into account the following aspects: photovoltaic system applications (for private house, residential buildings, dwellings in inaccessible areas, stand alone PV systems), financial support and profitability, environmental quality, efficiency and lifetime, architectural aspects.

It will take into account that in the geographical area of the Targoviste city, the average number of sunny days in a year is about 210 days and the available solar energy throughout the year is about 1200 kWh. Given the usual values of yield for the two conversion systems studied (photovoltaic panels and solar panels) students will be able to make simple calculations related to electricity or thermal energy that can be produced. It will compare the cost of energy produced by the investment cost, determinant the time interval payback; will consider the price of a kWh of electricity, about 0.6 RON.

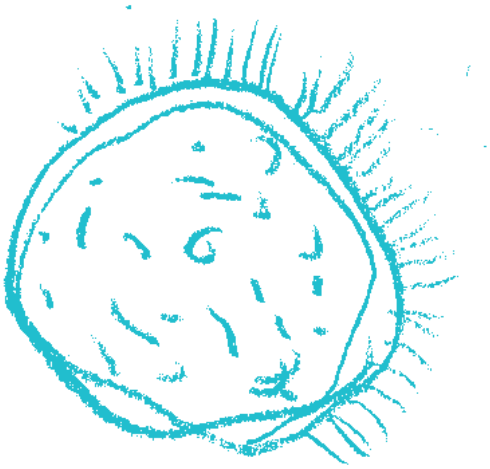
2. How do you evaluate the role of research in the field of solar energy conversion systems? What problems would be solved in this area?

The students will express their opinions regarding the status importance of the solar research area in the present, and they will mentioned their impressions for the future regarding the necessary improvements in this area.

Finally, students will complete a questionnaire for their activities evaluation.

3. Given the price of green energy production from Romania, what measures should we consider reducing the environmental pollution?

The students will present the measures to be considered for each of us to reduce the energy consumption.



The duration of this activity will be approximately 20 minutes.
The expected no formal activity allows to the students to acquire / to form new knowledge, skills, and attitudes regarding the followings:
a. Knowing the importance of the nanotechnologies in making solar energy conversion systems for the electricity or heat;
b. Understand the operating principles of studied systems;
c. The application of the new knowledge in assessing the role which it can have the green energy production in everyday of life;
d. Understand the need to achieve the energy savings to reduce the pollution.

The non formal learning outcomes:
- Understanding the ways of energy production about a clean methodology;
- Knowledge of the research and development opportunities which exist locally;
- Developing the interest for the study of the sciences and technologies.

Recommended training arrangements (described in formal business strategy):
1) Observation
2) Conversation
3) Explanation
4) Experiment

Aimed educational objectives

Aimed educational objectives	Non-formal learning activities
1. The understanding of the physical phenomena underlying the operation of photovoltaic and solar thermal panels	The presentation of these installations; the explain of the operation principles; use of explanatory posters
2. The knowledge of the physical characteristics of the studied installations	The performance description of each plant; the illustration on the concrete cases.
3. The applying of the new knowledge in the assessing of the costs of the green energy installation	The rules presentation for calculating the cost of the solar energy installations
4. The formation of a favourable attitude for the green energy production and for the reducing household energy consumption	The presentation of the conventional ways of the electricity and thermal producing

For the learning activities proposed under the formal activity, it is assumed that the students know: the energy sources (naturals and artificialness); the ways and methods of the electricity and heat producing; the environmental pollution and its effects.

Evaluation

This section provides suggestions to evaluate the non formal activity results, methods, techniques and tools exploited in this work.
The strategy evaluation can be designed for non-formal subtasks approach being tailored to their specific.
We recommend using feedback questionnaires, self-evaluative essay, tests of peer feedback, sheets of systematic observation of the behaviour and activity of the students, UN portfolio, etc.
The student's evaluation, in non formal subtask aims (at mention the objectives of this approach):
a) Assessment of general interest for science;
b) Evaluation of basic knowledge in science and technology domain;
c) Evaluation of the understanding level of new knowledge;
d) Evaluation of a specific language for the solar energy domain;
e) Evaluation of the assessment skills of performing simple calculations using numerical values and formulas used in non formal activity.

Evaluation strategy:

1. Oral evaluation of the understanding level of the new knowledge
2. Evaluation of the communication skills using the language related the experiments and phenomena
3. Evaluation of experimental skills
4. Review written by questionnaire

QUESTIONNAIRE REGARDING THE APPLICATION OF NANOTECHNOLOGY FOR THE ENERGY PRODUCTION DOMAIN

Please fill in as accurately and honestly as possible this questionnaire which will be used later as a tool for performing a case of study. We guarantee anonymity statement still required, these being our only necessary statistical processing of information provided by you.

1. Your student grade.....

2. Profile of the class (only for high school students):_____

3. Gender: F___ M___

4. Village type of origin:

a) small town, 30-100,000 inhabitants

b) very small town, with less than 30,000 inhabitants

c) village as common centre

d) village

5. What impact do you think to have the using of solar thermal technologies and photovoltaic technologies in the context of human health, environment protection and society evolution?

a. Beneficial b. Harmful c. No any consequences

6. What is the strongest argument for the development and use of solar energy conversion plants?

a. Solar energy is free

b. These plants do not pollute the environment

c. The appearance of the place where the architectural changes are well placed.

7. What is the strongest argument against?

a. Initial high costs

b. The geographical area in which we do not have a sufficient number of sunny days

c. We don't know well enough the benefits of their use.

8. Was your opinion changed on the importance of solar installations after the discussions on Amphitheatre?

a. Yes b. No c. I do not care

9. You've learned something new today?

a. Yes b. No c. I do not care

10. Where do you get more information on the topics discussed today?

a. Teachers of Sciences b. Parents c. Internet d. Reference Books

11. How do you assess the role of research in social development?

a. Very important b. A little important c. Unimportant

12. If you hold the amount required purchase of a solar installation at the apartment or house, you decide to purchase?

a) Yes b) No c) I do not know

13. Please indicate in writing which was the most interesting thing you learned today seen or studied.

4 Sources

Sources

- Giant photovoltaic array (pag. 2) - Image source: https://upload.wikimedia.org/wikipedia/commons/4/45/Giant_photovoltaic_array.jpg
- www.renewableenergy.com
- www.wikipedia.org
- www.icstm.ro
- www.energieverde.go.ro/
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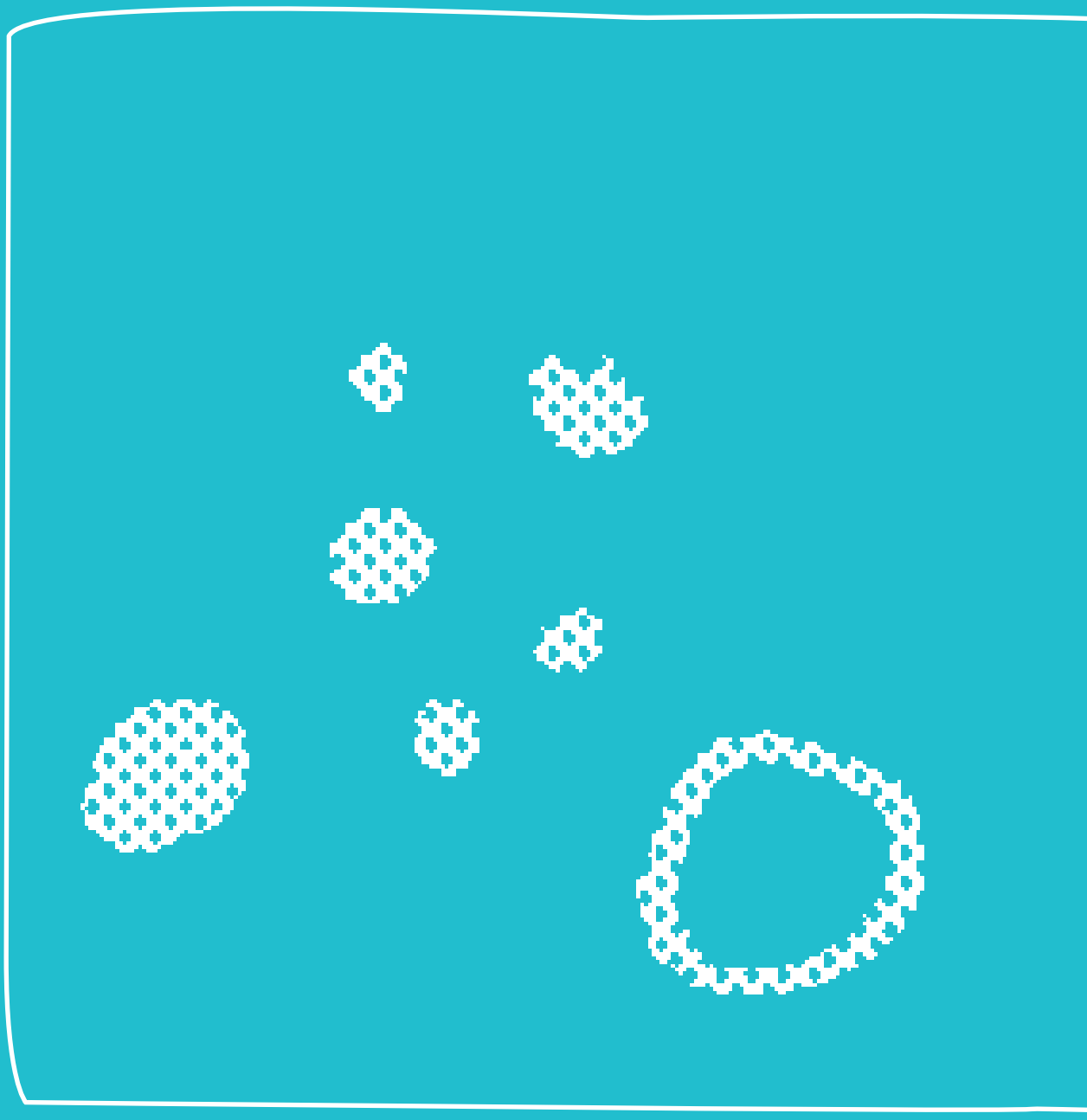
5 Colophon

Colophon

IRRESISTIBLE is a project on teacher training, combining formal and informal learning focused on Responsible Research and Innovation. It is a coordination and support action under FP7-SCIENCE-IN-SOCIETY-2013-1, ACTIVITY 5.2.2 Young people and science: Topic SiS.2013.2.2.1-1 Raising youth awareness to Responsible Research and Innovation through Inquiry Based Science Education. The project IRRESISTIBLE is funded by the EU as FP-7 project number 612367

www.irresistible-project.eu

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