USING OPEN SOFTWARE TO TEACH RESOURCE ASSESSMENT OF RENEWABLE ENERGIES

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Abstract

The University of the Basque Country (http://www.ehu.es) is the most important University in the Autonomous Region of the Basque Country, Spain. There is one degree in Renewable Energy Engineering given at the Gipuzkoa Faculty of Engineering (Eibar). In the last years of their studies, before becoming engineers, students have the opportunity to select a block of subjects intended to enhance their knowledge on Wind Energy, Ocean Energy, Biomass, Hydraulic Energy, Solar Thermal Energy, and Geothermal Energy.

These subjects are devoted to different aspects of the water cycle management, and geographical representations of wind, ocean, biomass, solar and geothermal energy resource. Apart from the transmission of good practices, the focus is practical and is based on hands-on computer real-life exercises, which involves not only intensive programming using high-level software, but also the spatial representation of results. To that purpose three main open source codes are used: QGIS (https://www.qgis.org/), R (https://www.cran.r-project.org/) and Octave (https://www.gnu.org/software/octave/). Students learn how to address real-life problems regarding geographical representation of wind and ocean energy resource with R, spatial representation of biomass, solar and geothermal resource with QGIS, and solar thermal system modelling using Octave.

The combination of learning by problems and learning by projects techniques, with publicly available databases, and the use of free software enhance the understanding of the problems associated with these energy resources, together with more freedom to improve self-learning.

Keywords: QGIS, R, Octave, learning by problems, learning by projects.

1 INTRODUCTION

During the last three years, students at Gipuzkoa-Eibar Faculty of Engineering in the Grade of Engineering for Renewable Energies (4 years) have many specialization subjects (http://www.ehu.eus/es/web/eibar). We will expose “Solar Thermal and Geothermal Energy” (third year), “Biomass” (second year), “Wind Energy” (third year), “Hydraulic Energy” (third year, in collaboration with the Faculty of Engineering of Bilbao) and “Ocean Energy” (fourth year), because of its interest in terms of the use of open software for the analysis of renewable energy resource and its geographical and spatial distribution. We must underline that the surveys of the students about the subject are generally outstanding.

- Solar Thermal and Geothermal Energy: The subject is divided in two different parts, each one related to solar thermal and geothermal energy, together with a last chapter related to the coupling of both technologies. The teacher uses learning by projects techniques, which involve the practical design of solar thermal and low temperature geothermal systems. The software for geographical information systems QGIS is a powerful instrument for the analysis solar radiation resources. We use satellite radiation data to evaluate the solar resource, together with LIDAR data to evaluate the shading patterns. Octave is also used to simulate the thermal behaviour of solar thermal collectors under varying thermal conditions. The ability of geographical information systems like QGIS, to manipulate geographical data is very useful for the representation of lithography, and the manipulation of energy extraction surfaces.
Biomass: teachers use learning by problems and learning by projects techniques during all the year (the evaluation is fully based on cooperative works on these projects). The software for geographical information systems QGIS is a powerful instrument for the analysis of biomass resource in specific regions taking into account even relevant variables for the extraction of wood.

Wind Energy: 30% of the subject is taught by learning by problems techniques in which the software R for statistical computation is a basic tool. It not only allows statistical calculation of wind energy production for certain turbines at specific locations, it also allows the geographical representation of wind energy.

Hydraulic Energy: 30% of this subject is also practical and based on learning by problems. Here the software EPANET is used in connection with R to study network of fluids, and management and maintenance of hydraulic systems. So the focus is practical with hand-on-exercises and all the teaching activities are closely interconnected with hydraulic systems and the maintenance of hydraulic energy plants.

Ocean Energy: 50% of the subject is practical based on learning by problems with R. Seven problems of two weeks are designed to solve along the 15 weeks of the subject about the wave, thermal gradient and stream energy potential of the sea in chosen areas of the world. We use satellite and mesoscale model data for that, and all the process is developed by step-by-step spatial representations of energy potential and bathymetric characteristics of the sea via R.

This includes handling two groups of skills:

1. Solving real-life problems like the correct design of the solar collection field, simulating the thermal behaviour of solar collectors under varying thermal conditions, and serial/parallel connection schemes; the correct design of water supply tanks, overall planning for a given area and water, wind, wave; biomass availability estimation under several scenarios. This implies the use of high-level programming software like Octave, EPANET and R.

2. Spatial planning and geographical characterization of available energy resources. This implies the use of a geographical information system (GIS) software and R, due to its modular nature holds the full functionality of any GIS software.

2 METHODOLOGY

When students select these subjects they have a reasonable degree of computing programming skills and they are already somehow familiar with general-purpose software like VisualBasic, Fortran or C++. Due to this initial background, it is possible for the team of teachers to design classes as a set of practical exercises within a bigger resource analysis project.

2.1 Octave

Octave is a high-level programming language intended for numerical computations, that can be very useful for solving sets of linear equations and dynamic models like the ones related to simulate the thermal behaviour of solar collectors. It is freely distributed under the GNU General Public License, and runs on most operating systems, like GNU/Linux, BSD, macOS, and Windows. It is largely compatible with Matlab, one of the most extendedly used numerical computation programs. It offers a fully integrated graphical user interface, and data visualization tools.

Additionally, Octave can be extended with new modules and functions already available, and the possibility of developing new functions. This way, Octave can be completely augmented and adapted to different objectives.

2.2 QGIS

QGIS is an official project of the Open Source Geospatial Foundation (OSGeo). QGIS provides a continuously growing number of capabilities provided by core functions and plugins. You can visualize, manage, edit, analyse data, and compose printable maps. Get a first impression with a more detailed feature list. This specific software for geographic information systems (GIS) purposes offers a more visual interface than R for geographical representation and spatial analysis. It can be a good complement of R to obtain a more understandable design in the presentation of maps, and to facilitate more visual operations than rough codes and scripts needed in R.
2.3 EPANET

EPANET is an open source code intended to model water distribution piping systems. EPANET is public domain software that may be freely copied and distributed. It is a Windows 95/98/NT/XP program, which can be installed without problems by the students in their own computers in order to work also at home. EPANET performs extended period simulation of the water movement and quality behaviour within pressurized pipe networks. EPANET's Windows user interface provides a visual network editor that simplifies the process of building piping network models and editing their properties and data. EPANET provides an integrated computer environment for editing input data. Various data reporting and visualization tools are used to assist in interpreting the results of a network analysis (https://www.epa.gov/water-research/epanet). It is worthwhile to mention that EPANET has made simple solving the type of non-linear equations involved. Before EPANET and similar tools this had to be solved using the Hardy-Cross method with successive approaches after a set of initial estimations of the unknowns.

2.4 R

R is a freely available software, that has turned out to be a perfect scientific tool due to its modular nature and its data processing capabilities. The reason for this is that R has a core module that can easily interact with an increasing number of packages, specifically developed by a growing amount of scientific communities that allow to take advantage of previous research. Due to the high potential of R, students feel that by incorporating R into their syllabus, they have gained access to a cutting edge, powerful and valuable tool that will make a difference in their professional career.

Additionally, R, apart from being free software, is continuously being developed with never ending improvements in the form of new packages that are adopted by an increasing number of scientific communities. After students have learned how to use it, they will become members of this huge community. Additionally, all the information on maps representation, bathymetry, wind data, wind rose representation, water management and associated spatial planning, is usually freely available and made public by regional, national and European institutions using Geographical Information Systems (GIS) standards, usually .shp files. For this reason, students need to effectively read this information, calculate results and finally, yield a spatial representation of the same. Packages like “sp” “rgeos”, “rgdal”, “maps”, “maptools” and “mapdata” have been developed to make R work with full functionalities just like any GIS software, while exhibiting all the capabilities of any high-level programming software.

2.5 Learning by problems and learning by projects

Using these programs to introduce concepts related to the subjects mentioned above, represents for our students a real and pragmatic way of problem solving. Taking into account Bloom's Taxonomy of Educational Objectives for Skills-Based Goals [1], they get a high level of expertise on ‘guided response’ and ‘mechanism’: 1) the student knows the steps required to complete the task, and 2) performs the tasks in a confident, proficient and habitual manner. The student simulates what the scientists do every day and use the logic of discovery instead of the logic of justification [2]. As Clement states [3,4], in his deep study on scientific creativity, when dealing with a problem heuristically there is no difference between the problem solving capacity of an expert and of a student. That is, the students should know the real scientific practice, and not only the final important and supposedly finished theories [5,6]. The state of the art in this domain has been developed very deeply in constructive problem solving via the use of analogy, visual thinking, spatial abstraction and other different heuristic instruments have been pointed out for that [7,8 9]. We will show that the mentioned software is a powerful instrument to implement this heuristics understood as the art for solving problems.

3 RESULTS

3.1 Octave for solar collector simulation

Students learn to read relevant climatic information from publicly available repositories, mostly solar radiation and outside air temperature. They learn how to simulate solar collector fields, using collector performance parameters, and surrounding environmental conditions. For example, Fig. 1 shows the variation of the thermal performance of solar collectors varying incident solar radiation and
temperature difference, and the evolution of temperature difference in a solar collector and performance related to water flow rate.

![Graphs showing performance related to climatic conditions and flow rate](image)

*Fig. 1. Performance related to climatic conditions and related to flow rate*

Students learn to simulate solar collector fields, and get a deeper understanding of the parameters that influence the thermal performance of the collectors, or the outgoing temperature of water.

### 3.2 QGIS for solar energy resource

In this case, geographic information systems (GIS) are very useful to place the information available and relate it to the surrounding conditions. Students learn to load and use publicly available information and to manage it to obtain useful information for their projects.

For example, Fig. 2 shows the thermal radiation for the Deba River’s basin, obtained from satellite data, and the inclination map for Ermua.

![Solar radiation map and inclination map](image)

*Fig. 2. Solar radiation from satellite data and inclination map for Ermua, from LIDAR data*

![Slope orientation and shading factor map](image)

*Fig. 3. Slope orientation, from LIDAR data, and roof shading factor for Ermua*
QGIS can also be used to calculate useful data from the available information. Using the r.sun integrated function, QGIS can be used to load inclination maps, and slope orientation maps from LIDAR data, to calculate the annual shading factors for roofs, as shown in Fig.3.

3.3 QGIS for geothermal resource

Geographic Information Systems are also very useful to quantify the low temperature geothermal resource. Lithology and surface calculations are the basis of the assessment of geothermal heat transfer capabilities.

Students can download the lithological information from public resources, load it to QGIS, as shown in Fig. 4, and use it for a first assessment of the most suitable areas for geothermal systems.

![Fig. 4. Lithology for the town of Mendaro and surface calculation around buildings](image)

Surface area calculations is also very useful for the assessment of the accessible geothermal resource. Since low temperature geothermal energy is a low quality resource, it can only be exploited in the nearby of buildings. The buffering tools of QGIS can be used to evaluate the area in the surrounding of buildings, as can be seen in Fig 4. Overlapping the lithological information with the accessible area, and usual conversion factors can yield the usable geothermal potential.

3.4 EPANET-R for hydraulic resource analysis

For example, students learn to read relevant information of water facilities from public institutions websites and at a second stage, they learn how to extract relevant information and put it on a map to represent, for example, river’s catchment or flooding areas (Fig.5).

![Fig. 5. Layout of Ebro River’s catchment and flooding areas in Bilbao city](image)

The skills they get include the estimation of water availability in the frame of climate change scenarios as provided by the last AR5 report and associated CMP5 models projections. Students learn how to download CMIP5 data from: http://climexp.knmi.nl/selectdailysseries.cgi?someone@somewhere. Furthermore, visual thinking is trained heuristically by the interpretation of the relation between altitude isolines and the catchment of the valley around the river along the gradient.
3.5 R for wind and wave energy resource assessment

Here students represent spatially the wind energy potential in terms of Capacity Factor of the offshore floating wind farm over the Iberian Mediterranean area. Or they represent the wave energy potential over the Bay of Biscay (kW/m) based on the TOPEX satellite data (see Fig. 6).

The skills they get include the estimation of energy resource and its spatial distribution, and the treatment of rough data coming from mesoscale models and satellites. Students learn how to download data of TOPEX from the NOOA (National Oceanic and Atmospheric Administration): https://www.nodc.noaa.gov/woce/woce_v3/wocedata_2/sat_sl/topex/docs/topex_doc.htm

The heuristic of this kind of maps is important because implicitly these colour representations are huge numeric matrices constructed by several operational variables in the R algorithm developed during many class hours.

![Fig. 6. Wind energy (Balearic Islands) and Wave Energy (Gulf of Biscay)](image)

3.6 QGIS for biomass resource

In this case, the learning by problems project intends to quantify, locate and revalue the available forestry biomass as well as the forestry and wood waste for its subsequent thermal energy production. As expected, as they belong to two different types of biomass (forestry and industry residues), it would not be logical to apply a unified calculation methodology. Before knowing for sure the thermal energy that could be obtained from woody origin biomass, a free software program called QGIS will be used to find out the wooded area of the region (Figure 7). The restrictions of protected areas and nearness of roads are taken into account, together with the location of forest species, in order to calculate different biomass resource options over their intersections.

![Legend](image)

**Legend**
- Forested areas
- Protected areas
- Farmland
- Urban areas
- Forest areas
- Wood waste
- Wooded areas

![Fig. 7. a: Wooded area, b: Wooded areas and urban areas](image)
Heuristically speaking, the logical construction of the inner algorithm in order to superpose several geographical layers with different levels of priority in the forest establishes a creative hands-on activity for the visual representation, which is specified locally in each region and type of forest.

4 CONCLUSIONS

We have applied these learning by projects techniques in the Grade of Engineering for Renewable Energies for the last four years in the subject of “Solar Thermal and Geothermal Energy”. Taking into account that there are approximately 70 students per course we are speaking about more than 250 students, which have shown very good opinions in their surveys when they have been questioned about these subjects and the teaching methods used.

REFERENCES