



Use of Various Software Tools in an Alternative Energy Systems Course

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Abstract

A course about alternative energy systems and applications was developed and has been taught for the past four years at Grand Valley State University. The course, which has been taught as a four credit hour technical elective course in engineering, has been offered in various formats, such as simply a four contact hour course and most recently formalized as a three-lecture three-lab-hours format. Invariably though, the course involved case studies and semester projects. These projects have been mostly about feasibility studies on applications of such energy resources to real world problems. Several software tools have been acquired and implemented for simulation and analysis. These include such programs as PV f-Chart, f-Chart, and TRNSYS as well as Idaho National Laboratory's Wind Energy Analysis Program, which are being used in the enhancement of student training and learning in the course. This paper discusses the use of such tools in satisfying the objectives of the course and the assessment of the use of such tools from the instructor and student point of view.

Introduction

As a result of the increased interest in alternative/renewable energy sources in recent times, many colleges and universities have been offering various courses related to the fundamentals and applications of alternative and renewable energy sources. Even minors and certificate programs are being offered in various institutions ranging from community colleges to doctorate granting universities. Parallel to these initiatives, a host of textbooks and professional reference books are now widely available in the market with new ones being introduced steadily. These books tend to cover various selections from a wide spectrum of topics to different levels of depth and breadth as well as from different aspects such as technical, economic and environmental. At Grand Valley State University a four credit hour upper division undergraduate technical elective course was developed and taught since fall 2009¹⁻². The course was initially offered on an experimental basis as a four credit four contact hour course for a couple of times before a final format of 3-lecture and 3-laboratory hour format was approved. In addition, during the last two offerings of the course, graduate students were also admitted to the course under arrangements of special topics while the proposal for formally establishing the course as a dual listed undergraduate/graduate course has been going through the pipeline.

The laboratory portion of the course is well developed with special training units from US Didactic, Inc. on solar photovoltaic (PV), wind energy and hydrogen energy trainers on each of which multiple experiments are conducted³. Additionally the laboratory is equipped with a Heliocentris Fuel Cell Instructor System⁴, a grid-tied solar PV array of 12 Unisolar ES124 panels⁵ rated at a total of approximately 1.5 kW and a grid-tied SWIFT⁶ wind turbine. Over the past several times the course has been offered, the experiments conducted in the laboratory sessions have been well developed and matured.

One of the course requirements for the undergraduate students enrolled in the course is completion of a semester-long team project. The projects are usually assigned on practical applications of solar thermal, solar photovoltaic or wind energy and involve a feasibility analysis. Occasionally other topics such as applications of ground source (geothermal) heat pumps have also been used in student projects. Until the last offering of the course in fall 2012, no specialized software tools were introduced or required to be used in the course. Until then, only one undergraduate team ventured to explore the use of PV F-Chart software for which the college has a perpetual site license. In addition, a graduate student was assigned an individual project in which he had to learn how to use TRNSYS⁷ (Transient System Simulation Tool) – another software package available for students' use in the college – and perform a case study on a solar thermal system design for satisfying a specified ratio of the total heating load of a residential unit from solar energy.

In the last offering of the course three software packages/tools were formally introduced and the students were assigned to acquaint themselves with these tools and carry out a different case study using each of these programs. In what follows a discussion of each of these programs and the case study assigned requiring the use of each of these will be presented. The degree of success in completion of the case studies, the feedback obtained from the students in the class by administering an end-of-semester survey conducted specifically on the requirement of the usage of these tools will also be presented. The instructor's suggestions of how to better implement usage policies will also be discussed.

Use of Various Software Tools

During fall 2012 the students in the Alternative Energy Systems and Applications course were required to use three new software tools one of which is in public domain and two for which the college has acquired the perpetual educational license. The former is an MS Excel based energy analysis program developed by the Idaho National Laboratory (INL)⁸. The latter two are F-Chart⁹ and PV F-Chart⁹ programs for which the licenses were acquired from F-Chart Software, LLC. A brief description of each of these is presented next.

F-Chart Software

F-Chart is a computer program that can be used for the analysis and design of an active or passive solar heating system. The program is an implementation of the methods developed at the University of Wisconsin Solar Energy Laboratory and can be used to estimate the long-term average performance of domestic water heating systems, pebble-bed storage space and domestic water heating systems, water storage space and domestic water heating systems among other systems. Weather data for hundreds of North American locations, the 16 California climate zones and numerous other locations are included with the program. Users can add new weather data. For analysis, the input data is entered through a graphical user interface. The most important technical analysis performed by this program is the determination of the solar fraction (f) for a given application/system, which represents the fraction of the heating load that is obtained from solar energy, hence the method being called the F-Chart method. The program also performs a detailed economic analysis based on user specified parameters. Hence the user

can determine whether a proposed solar thermal system has a reasonable payback time. A users' manual in .pdf format is available for users. This manual includes information on how to get started, commands, parameter sets, system and output descriptions and economic parameters and outputs. The manual includes example problem set ups.

PV F-Chart Software

This program was also developed at University of Wisconsin Solar Energy Laboratory and implements similar methods as F-Chart program but for solar PV systems rather than solar thermal systems. It can be used to analyze and design utility interface (grid-tied) systems, battery storage (stand-alone) systems as well as systems with no utility interface or battery storage. Similar to the F-Chart program, PV F-Chart program is equipped with extensive weather data. Besides weather data the other input data is entered through a graphical user interface. The users' manual, also accessible in .pdf format, provides an introduction, example case set up, commands including load menu commands, system and output descriptions, economic parameters and output as well as algorithms on monthly-average array output, monthly-average excess energy, effects of load variability and battery storage systems. Detailed economic analysis can be performed based on user specified parameters.

INL Excel Wind Energy Program

This MS Excel based program was developed at Idaho National Laboratory. It is in public domain and can be downloaded from INL's portal. The program is useful for estimating the potential of electrical energy generation at any site for which there is statistical wind data. The input data requirements include average wind speed, standard deviation of wind speed and average wind direction. In this format, INL's web site provides 10-minute averaged wind data for multiple locations in the states of Idaho and Utah as well as for Vandenberg Air Force Base, Lompoc, CA. For new users these data sets can be conveniently used for performing case studies. The program stores sizeable data representing the power curves of multiple commercial wind turbines from multiple manufacturers. Additional power curves can be provided by the user. These can be used for estimating the total energy generation expected from the selected turbine annually as well as for the entire period for which wind data is supplied. It is possible to extrapolate wind data from the actual measured data at an altitude to those at desired hub height by a power law relationship by the use of user specified wind shear coefficient. Another performance metric determined is the capacity factor. Wind speed frequency distribution and distribution of the fraction of energy generation with wind speed are also presented as part of the output in addition to other statistical output data. Through the use of an additional executable file provided by INL one can also generate the so called wind rose, which depicts the distribution of wind direction and speed at a location over a period of time.

Case Studies

For each of the three software tools described in the previous section a case study was assigned to the students. The students were asked to work on these case studies during particular laboratory sessions and if needed on their own time. They were provided only limited amount of specific information on the problems and were to learn how to use the programs on their own in

the case of F-Chart and PV F-Chart. In the case of INL Wind Energy program a classroom demonstration of how to download the Excel program and a particular data file was performed. Below are the brief descriptions of the case studies.

PV F-Chart Case Study

The students were assigned to perform a comparative analysis of a solar PV array to be used in a residential unit at two different locations of the continental US with considerably different climate conditions and solar irradiation availability. They had to start with the average annual electricity consumption of a typical residential unit and determine the monthly load by distributing the overall load uniformly over the year, though it is possible to specify a variable monthly load by the user. For this first time assignment they were allowed to choose any reasonable simplifying assumptions about daily variation of the demand for electricity. One of two possible approaches was to be selected by each student. One approach was to target the same overall solar fraction to be satisfied at each location. This would lead to a comparison of the size of the array (number of PV panels) needed for each location and the corresponding economic analysis. The second possible approach was to consider an identical solar PV array at both locations and determine and compare the overall solar fraction that would be obtained for each location. An economic analysis was to be performed for this approach also. For this, an expected life time of 25 years was to be considered for the solar PV panels. The students were asked to determine whether the proposed projects would have a realistic payback period or not.

F-Chart Case Study

The case study assigned for this program was a follow up to an earlier homework assignment in which a problem from the textbook was to be solved by the use of F-Chart method but without using the F-Chart software. In this problem the monthly heating load of an office system was specified for the student's hometown and he/she was asked to determine how many of a specified model of solar collectors would be needed in order to satisfy 50% of the overall heating load from solar energy. In the previously assigned homework the students had to use the F-Chart method but performed the monthly and overall annual analysis by using computational tools such as Excel. In the case study they were required to solve the same problem using the F-Chart software.

INL Wind Energy Program Case Study

In the case study assigned the students were to carry out a comparative analysis using INL Wind Energy Program. Just as in the case of the PV F-Chart case study the students could choose one of two possible approaches. One of these was to consider the same wind turbine model at two different locations and compare the performance of the same turbine, including the average annual energy generation and the capacity factor at the two locations. The second possible approach was to compare the performance of two different wind turbines at the same site. These could be either wind turbines of different power ratings from the same or different manufacturers or turbines of similar power ratings but from different manufacturers. In each case the students were to interpret the results generated by the program. The INL Excel Wind Energy Program produces a summary results page, which contains the cumulative results for easy interpretation.

Due to the fact that the INL Wind Energy Program requires wind speed, standard deviation of the wind speed and direction at regular intervals, students chose statistical wind data of different sites that are accessible from INL's web site as mentioned before.

How Did the Case Studies Go?

In the case of PV F-Chart and F-Chart software the students were not provided any information on the use of software other than which laboratories they could access the software from and that a users' manual in .pdf format was accessible on-line. They had to rely on their own learning from the example problem set ups in the manual. For these two case studies the students were given a total time of approximately four weeks to complete their studies. The case study on PV F-Chart was assessed and a chance for submitting an improved version of the analysis and report was provided. Because there was quite a bit of confusion about how to define and set up the electrical energy load distribution in the program. Once this was explained in the class the revised reports indicated significant improvement in successfully simulating the assigned problem.

In the case of F-Chart case study, it was rather easy to come up with a significantly different answer for the number of solar collectors needed for a target solar fraction from what the students obtained by previous analysis without the use of F-Chart software. The reason for this is that besides the solar collector characteristics – the slope and intercept- of the collectors as provided by the Solar Rating and Certification Corporation [], the problem set up involves numerous other parameters, which were not necessarily well known; and choosing default values would not necessarily work well. Since the software has a wide range of applications that can be analyzed it is necessary to master to a certain degree the parameters that need to be set up for the right analysis. Among the three case studies this was the one that caused the widest variation in the answers the students obtained for the assigned problem. Only two students out of nineteen got results close to the ones they obtained without using the F-Chart software. It is obvious that a better understanding of the process of setting up the case study properly will be needed.

The INL Wind Energy case study was carried out with no major difficulties even though the program had been developed in an earlier version of Excel using macros and some adjustments were required to make it work on the recent versions of Excel. Some of these necessary adjustments were pointed out in the class in a demonstration of downloading and installing the program as well as importing wind data files into the program. The students figured out how to overcome the remaining issues. The case studies went reasonably well. The only significant error made by a few students out of carelessness was to not take into account the adjustment needed for the hub height of the turbine and ending up having a hub height smaller than the radius of the turbine rotor (which would obviously not work) or only slightly larger (which would not be a good choice).

Student Survey

In order to better gauge the students' opinions and try to improve the learning experience they may obtain from the use of the software tools discussed in this paper, an end-of-semester survey was conducted. Seventeen out of nineteen students were present to complete the survey. The

survey consisted of 18 questions. The first 12 of these were repetitions of the same 4 questions posed for each of the software tools. The answer to each one of these questions was to be given on a scale of 1 to 5, where a “negative” response would correspond to a lower grade and a “positive” response to a higher grade on the scale. These 4 questions were as follows:

Question 1: How useful/beneficial was the use of INL Wind Energy Analysis software to you?

Scale: 1 (Not at all) to 5 (Very much)

Question 2: How user friendly was the software? **Scale: 1 (Not at all) to 5 (Very user friendly)**

Question 3: How reasonable was the time spent on learning to set up a case study? **Scale: 1 (Too excessive) to 5 (Very reasonable)**

Question 4: How easy was the interpretation of the results obtained? **Scale: 1 (Very hard) to 5 (Very easy).**

The answers to these questions are summarized in the form of pie-charts in Figures 1-4. The same 4 questions were asked for PV F-Chart software in questions 5 through 8 respectively, and for F-Chart software in questions 9 through 12 respectively. The responses of the students are also summarized in the pie-charts depicted in Figure 5-8 and Figures 9-12 respectively.

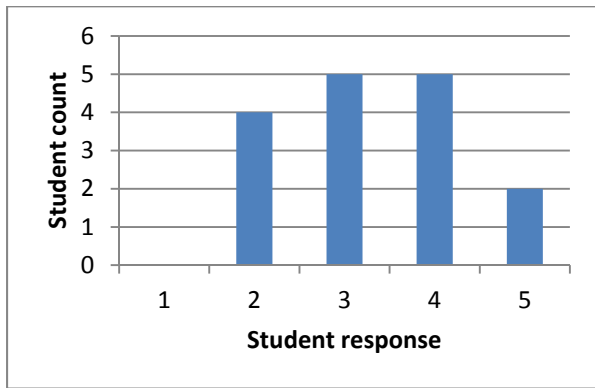


Figure 1. Responses to Q. 1 INL Wind

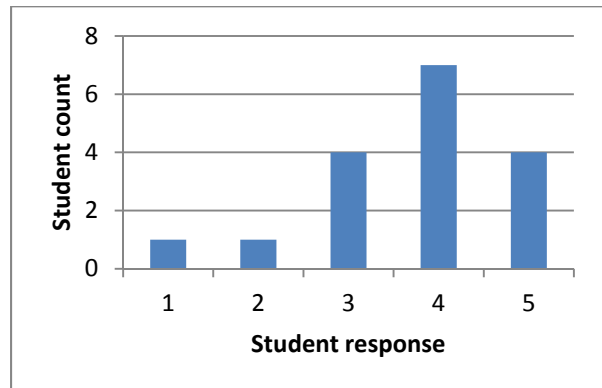


Figure 2. Responses to Q. 2 INL Wind

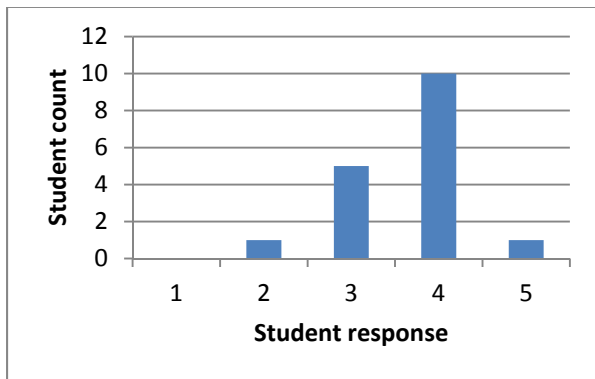


Figure 3. Responses to Q. 3 INL Wind

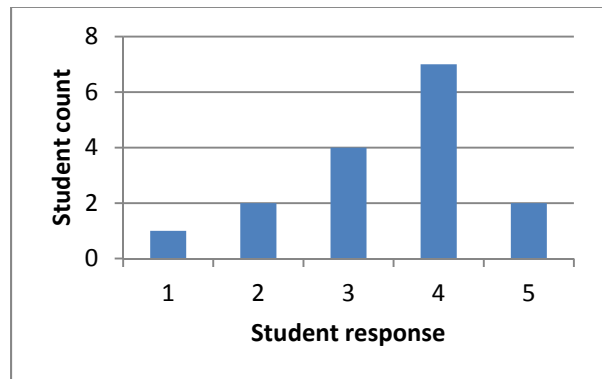


Figure 4. Responses to Q. 4 INL Wind

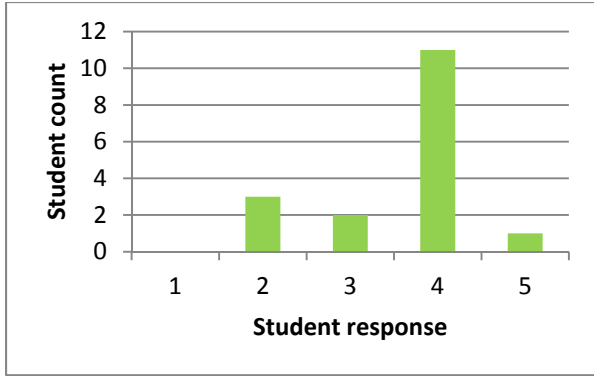


Figure 5. Responses to Q. 5 PV F-Chart

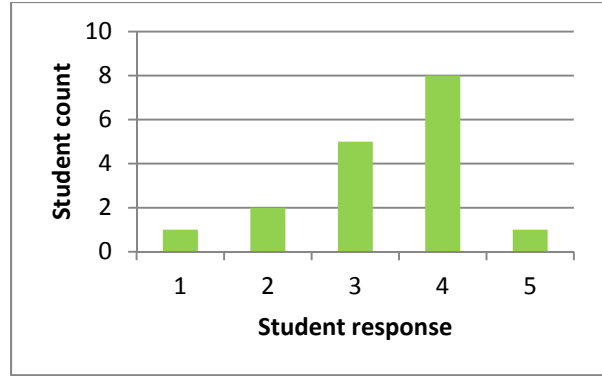


Figure 6. Responses to Q. 6 PV F-Chart

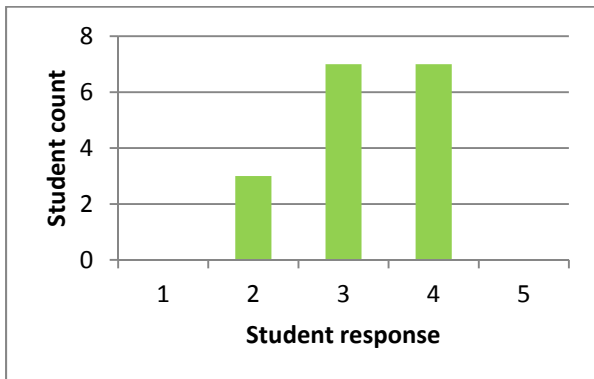


Figure 7. Responses to Q. 7 PV F-Chart

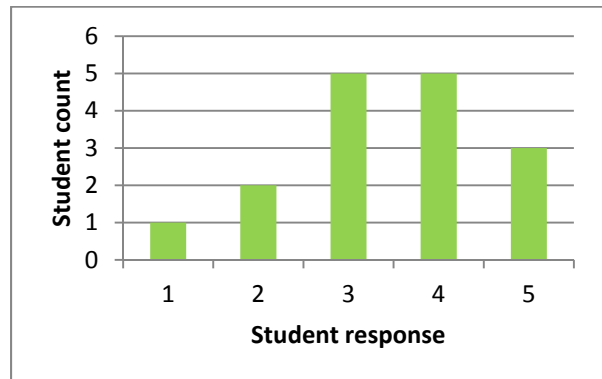


Figure 8. Responses to Q. 8 PV F-Chart

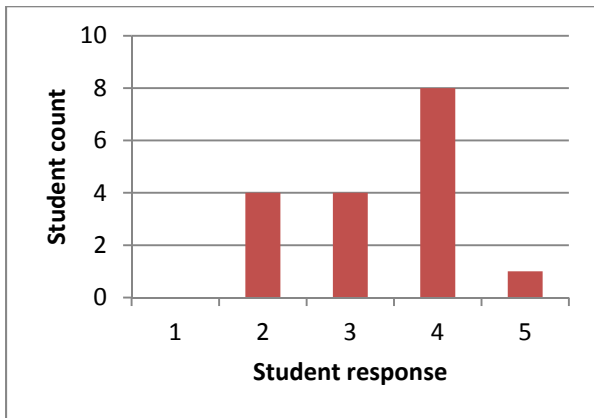


Figure 9. Responses to Q. 9 F-Chart

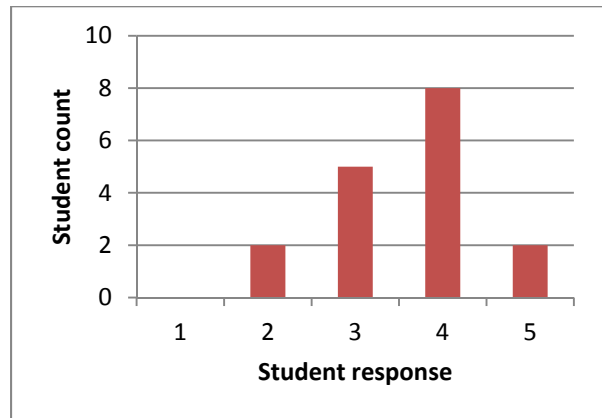


Figure 10. Responses to Q. 10 F-Chart

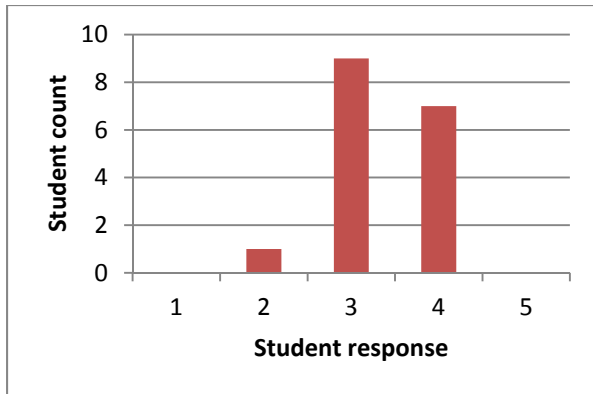


Figure 11. Responses to Q. 11 F-Chart

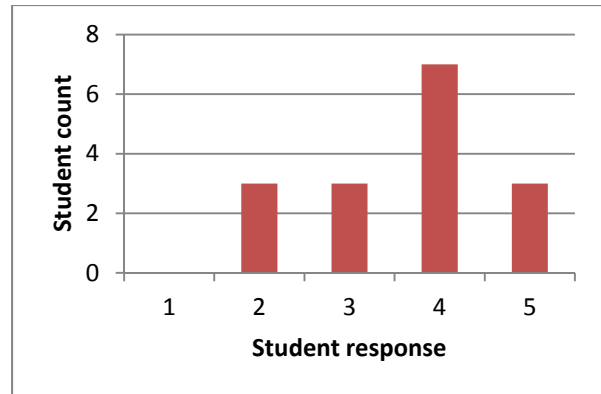


Figure 12. Responses to Q. 12 F-Chart

In Question 13 the students were asked which of the three software tools they found to be most beneficial. The responses are presented in Figure 13. Question 14 asked about why. There were variable responses. Some of these are as follows.

F-Chart:

“I personally like to utilize solar collectors in my house someday. This study gave insight into what could be expected for performance and operation.”

“I was able to produce graphs without any errors, and also understand the data summaries easily.”

“F-Chart was the most beneficial to me because I would be more likely to consider a solar system along the lines of this analysis for my residence as opposed to wind turbines or PV panels.”

“The inputs were relatively simple and self explanatory. PV F-Chart was similar, but it was more difficult to find data for the PV module to input.”

INL Wind Energy:

“It was the easiest to use and understand.”

“This was the most user friendly and easiest to interpret.”

PV F-Chart:

“I felt it was the most likely software that I would use outside of class. Getting the parameters set was a little bit of a task but the .pdf was helpful in getting through those steps.”

“The software seemed to be most user friendly but was similar to F-Chart”

“It allowed me to further my learning about PV cells.”

“I thought the results of this were easy to interpret and provided the best application toward visualizing the setup of a PV system.”

“This software seemed to be the most relevant with the information that it provided.”

“Results made sense.”

“I feel the program is much more beneficial since it really helps see how well solar PV can be used, as well as why it sometimes shouldn’t. The F-Chart is a close 2nd for the same reasons.”

Question 15 read “Which of the above software did you find easiest to learn and set up a case study?” The responses are presented in Figure 14.

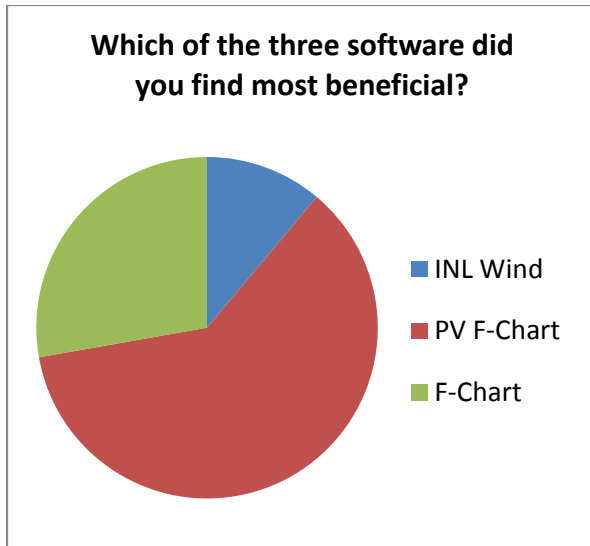


Figure 13. Responses to Q. 13

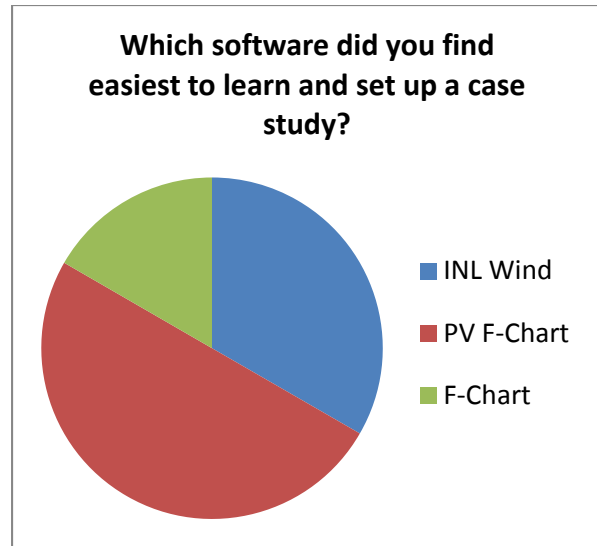


Figure 14. Responses to Q. 15

The remaining three questions that were asked in the survey were as follows:

Q. 16. “What did you like best about these software tools? What did you like least? Please try to be specific about each.”

There was a large spectrum of responses to this question. There was no consensus for any one of the programs being user-friendly or easy to set up a case study or interpret the results. Some students commented that these tools were very beneficial for setting up real-world problems and obtain real-world answers, some liked the fact that F-Chart and PV F-Chart could provide economic analyses, some students recognized the power of easily doing parametric analyses or comparisons very easily. On the negative side, some students complained about various software not being very user-friendly, macros of INL Excel program being glitch, or PV F-Chart and F-Chart being “buggy”, or having too limited location data – in the author’s opinion the student may be referring to available wind data in the format required.

Q. 17. “This was the first time official case studies were assigned that required the use of these software tools. Thinking back, what improvements would you suggest in order to make the use of them more beneficial to the future students taking this class?”

In the responses to this question, there was a general feeling that the case study objectives be made clearer. Some students suggested that the instructor go through an example case study in the class for each program before assigning one to the students. Some suggested a little more direction as to how to set up a case study in each software tool. A few students even suggested that the specifications of the solar PV panels be provided to them rather than they doing the research to obtain that information.

Q. 18. “Should the use of such software tools be continued? Should additional/alternative software tools be introduced in future? Do you have any in mind?”

The response to this question was overwhelmingly positive. Only one student felt that the use of such software tools should be discontinued. Two students suggested that the INL software should be updated, one suggesting that if it can't be updated it should be scrapped. One student felt that PV F-Chart was too confusing and should be dropped. One student suggested that a program that can be used for analyzing geothermal heat pumps would be a nice addition.

Concluding Remarks

From the first time experience of utilizing the three software tools discussed in this paper the author feels it is safe to conclude that the use of such tools is definitely beneficial and should be continued. A great majority of the students appreciated this fact also. As a matter of fact all undergraduate students that had a team project related to solar PV applications used the PV F-Chart to perform part of their design analysis. The students who had a wind energy projects intended to use INLWind Energy program but due to the location of their feasibility study they could not obtain wind data in the format required by this program, and so they had to develop their own analysis programs. The author is planning to continue making the use of these software tools in the aforementioned course with some improvements. Valuable lessons were learned from this trial as to what kind of difficulties the students have encountered and what kind of adjustments need to be made in order to make the use of these software tools both enjoyable and beneficial to the education and training of the students.

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