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Some Implications of the Use of Renewable Energy in Production Scheduling

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Abstract
In production processes, electricity is an essential resource. In most cases, companies rely on an energy supplier whose energy, usually, comes from a non-renewable source. This dependence could limit the companies' production due to energy constraints during peak hours and contracted demand. These two restrictions can cause blackouts and/or power outage issues that increase setup operations and generates more makespan and work in process. The RCPSP/πRC model exemplifies the last situation by adding a setup operation after each activity to represent the effects of energy constraints in the production scheduling. The use of renewable types of energy can remove these restrictions and eliminate the increase in setup operations; nevertheless, dependence on source availability represents a new restriction. In this paper, the authors recreate the process under two different conditions using simulation modeling; the first one under regular energy constraints and the second one under renewable energy constraints. The use of the suggested model shows a decrease of 16.49% in the machine's down percentages. Also, the machine use increases from 14% to 16% by working under renewable energy constraints. Concerning future lines of investigation it is proposed that the plausible verification of the achieved increment will reduced the process' cycle time.

Keywords
Energy Constraints, Non-renewable Energies, Production Scheduling, Renewable Energies.

1. Introduction
Industrial growth has had a negative impact on the environment due largely to the consumption of non-renewable sources for energy production. This impact is mainly reflected in phenomena such as climate change and global warming which in addition have consequences such as an increased global temperature, contamination of drinking water and crop losses due to severe drought, among many others effects.

About a quarter of the total energy used globally is consumed by manufacturing companies (Schmid 2012). Within this context, different alternatives for the production and management of energy in the manufacturing industry arise. The interest generated by the implementation of renewable energy in industrial and domestic levels (with solar panels) has steadily increased, considering the scenario previously exposed. On the other hand, the concept of energy efficiency has also experienced a significant boost due to the increased costs of energy consumption, precisely because of how expensive it is to generate and distribute energy. Some studies indicate that the average energy price has increased, for example, between 2004 and 2007 by 35% (Vinh et al. 2012). That is why many organizations are looking to reduce their current consumption, in order to reduce their electric bill and offset their environmental impact. (Fysikopoulos et al. 2014).

The International Energy Agency (2015) defines renewable energy as the energy that is derived from natural processes (e.g. sunlight and wind) that are replenished at a higher rate than they are consumed. Solar, wind, geothermal, hydro, and biomass are common sources of renewable energy. On the other hand, non renewable, or traditional energy availability is limited, takes millions of years to form and will run out one day. New trends are published every day commenting the idea that energy future will be powered by abundant, renewable wind and sunlight due to its properties and benefits over traditional energy generation. The use of renewables can reduce fuel imports and insulate the economy to some extent from fossil fuel price rises and swings (IEA, 2013).

There are certain characteristics that renewable energies present. First, these types of energies are intermittent, which means that the direct source of energy is an external factor that cannot be easily controlled such as solar irradiation and wind speed. This implies that this type of energy depends on the availability of input and also on the fact that it cannot be stored. In contrast, fossil fuels are storable and their access is not flashing so both options have different costs (including installation) and availability (Ambec, Crampes 2012).

In recent years, there have been multiple investigations covering economic and environmental implications of using clean energy in industries, which are focused on reducing energy costs based on the use of renewable energy and reducing carbon dioxide emissions as well as pollutant gases to the atmosphere. The latter has been largely studied given that the research in alternative energy sources arises precisely from a natural condition, as is the scarcity and future extinction of fossil fuels. However, several authors have introduced the option of not only taking environmental damage into account but also including cost reduction alternatives of using renewable energy.

On the other hand, energy constraints are understood as the conditions under which access and use of electricity are limited. In countries where electricity rates vary over time according to demand, energy consumption during peak hours is a limiting factor in enterprises, since production at this time has a higher cost. A restriction in the budget is a way in which this could be addressed, considering that the capital invested in energy consumption should be limited, because as mentioned before, the electric rate is increasing and most organizations aim to reduce costs. On the other hand, energy consumption in setup operations should be considered because of its impact on cycle times, and has not been as developed as the budget restriction.

This article summarizes relevant and recently conducted scientific research in section II, mostly about the advantages commonly presented when talking of renewable energies, the energetic restriction that affect companies' production and how organizations take action in counteract the constraints using energy efficiency. Section III includes the research proposal, which is based on the results obtained in the previous research. The theoretical critic to the RCPSP/πRC model was conducted in section IV. In section V the validation of the model through simulation using the software Promodel is described. Section VI proceeds with the analysis of the results found from the simulation. Finally, the conclusions of the complete research and the future lines of investigations are established.

2. Framework

2.1 Implications of the use of renewable energy in the manufacturing industry

According to literature found nowadays, the manufacturing industry focuses its research efforts on the economic and environmental advantages and disadvantages of the utilization of renewable energies. Also, there exists research about its economic advantages compared against the ones gained using fossil fuels.

The International Energy Agency (2008) stipulates that manufacturing is responsible for over 33% of world total energy consumption and 38% of direct and indirect CO2 emissions worldwide. That is why, in recent years there has been a growing interest in exploring alternative energy sources, such as renewables, that can minimize their environmental impact as well as the consumption costs.

Renewable energies have about zero greenhouse gas emissions and air pollutants, also they have no problems with long-term disposal of waste and present no risk of catastrophic accidents (Delucchi and Jacobson 2013). Considering that by 2050 the use of renewable energies such as hydraulic, wind, solar and biomass in power generation is projected to contribute in reductions in emissions between 9% and 16%, and that the share of renewable energies in the generation increase from currently 18% to 34% in 2050 (Baratta 2011), studies have been conducted to the economic impacts of the various renewable energy industries, as well as advantages or benefits of its availability.

Part of the economic benefits that have been raised in the literature are that the cost of energy from natural resources could become, by 2030, 10 cents per kilowatt-hour or so compared to the energy obtained from fossil fuels (Delucchi and Jacobson 2013). Moreover, Schmid (2011) mentions that by using energy developed from natural resources there would not be an urgent need to control energy consumption by the company. However, in economic terms, he is taking into consideration the cost of the initial investment.

Beerbuhl (2014) mentioned that renewable energies are intermittent and that introducing this type of energy requires new techniques and technology knowledge. Within the production planning, this has to be taken into account at some point to reach no effect on production. Despite the above, it is important to know that the energies from natural resources have the same reliability and are cheaper than the current system based on fossil fuels (Delucchi and Jacobson 2013).

Also, there have been studies as the one developed by Fazleena et al. (2014) where assessment methodologies for sustainability performance of manufacturing processes are created by incorporating metrics to quantify and measure the value of sustainability in economic, environmental and social terms.

It can be seen that there are several cases, such as those presented by Trentesaux and Vittal (2014) and Fazleena et al. (2014), where it has been shown how manufacturing operations can contribute to the sustainability of a company and thus benefit its economic, environmental and social matters, where the use of renewable energy is used to support the above. However, it has not been clearly exposed how the use of renewable energy can affect or contribute to restrictions that companies have regarding matters of energy consumption during peak hours, limited budgets, energy consumption in the setup operations or preparation and dependence on energy suppliers, among others.

2.2 Energy Restrictions in Manufacturing

Every industry must properly manage the resources used in their productive processes, especially if one of the resources is limited or scarce. Electricity is a vital resource in most activities involved in production, and in many cases, it is the most restrained. These restrictions are economic in most cases, and they affect the company's productivity and compromise the final good or service.

Okubo (2015) identifies three main energetic constraints: an energy consumption constraint during peak hours, a contracted demand restriction, and an energy consumption restriction during setup tasks.

The first constraint consists of the production scheduling during the peak hours of energetic demand, in which the electric rate is usually higher. This constraint impacts production as many firms decide to reduce or shut off their production during on-peak hours in order to reduce their electric bills. These measures increase the amount of work in processes and, hence, increase the cycle time as indicated by Little's Law (Hopp, Spearman 2000). In addition by increased setup and machines times, the existence of this constraint adds power outages, which rise the lead time, as the batch production is discontinuous.

Okubo (2015) points out that the second constraint is related to the first one. The high "on-peak hour" rates affect the budget compliance outlook. In many countries, firms must pay for the peak of electricity consumption, in terms of kilowatts, which is known as contracted demand. The energy consumption during setup tasks is affected by the energy outages that result from these two constraints. Most of the energetic consumption in a firm corresponds to the machine's setup operation, and the time spent waiting for it to achieve maximum power in order to produce; the existence of multiple stoppages in production scheduling increases the frequency of setups, which at the same time has an impact on the firm's energy bill. Ambec and Crampes (2010) indicate that these restrictions are the result of the organization's dependence to one energy supplier, as depending on an external source of electricity may be risky for production.

Moreover, the volatility of the fossil fuel, crude oil and energy derivatives, and the geopolitical risks in the petroleum producing regions, provokes energetic fragility and insecurity, and may affect economic performance. Mourshed (2012) studies the case of Bangladesh where in the period that spans from January of 2011 to March 2012 companies suffered blackouts almost every day. It is fundamental for developing economies to ensure electric access and to minimize energetic insecurity in order to provide conditions for continuous production and reduced makespan. Because of these blackouts, Bangladeshi companies were forced to incur additional costs, as they had to work in extra shifts to finish their production commitments, and as they had to setup their machines multiple times during the day. This is particularly harmful for a set of industries where work in process must be reprocessed or discarded. As a consequence, these industries are forced to buy larger quantities of supplies, which affects the waste percentage included in the MRP, as well as the reprocessing operation affects cycle time and the quality of the final product.

Due to these energy constraints the necessity of designing and developing new and smarter ways that allows an efficient use of time and resources is evident. The presented context leads some authors, like Artigues, Lopez and Haït (2009) to talk about energy reasoning, known as "Constraint Satisfaction Problems" (CSP). The main objective of the CSP is to accelerate the search for a suitable program to detect inconsistencies quickly and to reduce the effects generated by the restrictions. Brucker (1999) identifies the need to devise a schedule of projects for companies working under the model *make to order* where inventory capabilities have been diminished to work under a lean model. Although initially it is a model for project scheduling, this is homogenized for use in sequencing problems. With the notation explained in the previous article methods proceed to create a new model of low energy consumption restrictions known as Resource Constraints Project Scheduling (RCPSP). Okubo and Miyamoto (2015) propose a model of energy consumption taking into account the setup tasks and other energy restrictions for a certain period of time. This variation of the RCPSP model is proposed with the use of partially renewable resources (RCPSP / πRC). This last condition adds a time between two consecutive nodes or activities in order to evaluate constraints and if these constraints affect the mentioned time. Fang and Lin (2012) expressed that the problems of production scheduling can be adjusted by the rotation speed permitted on the machines. It is said that this speed can be adjusted during the execution of the machine and can be played by reducing electricity costs by sacrificing the delivery time and the complete delivery orders.

To counteract the effects generated on the production scheduling and productivity of the process, measures of energy efficiency such as those that will be mentioned below are being implemented in factories.

2.3 Constraint control through energy efficiency

Amory Lovins promotes the concept of energy efficiency, "using less energy to produce greater economic output". It can be expressed as the ratio of useful energy units produced and the energy consumed in the process (Yang and Yu 2015).

In the study by Fysikopoulos et al. (2014) an approach to achieve energy efficiency in manufacturing by dividing the study into four levels such as the level of process, machine, production line and factory is proposed. This study presents the alternative of using machinery that is capable of switching to eco-mode during the idle times, or that can be turned off when not in use, in order to reduce energy consumption. But this last option is subject to analysis because the energy required for the restart of the machine is greater than the energy consumed once it is underway, so the option to turn off the power is viable only if the time the machine will be out of use is greater than a certain critical time interval. Otherwise, it is more efficient to use the eco-mode.

Now, with regard to the restriction of budget explained above, this same study indicates that electrical control policies and varying rates at peak demand has complicated the optimization of production scheduling considering that there are cases in which an optimization of energy consumption does not necessarily imply a decrease in the electricity cost.

It is important to make the difference between energy efficiency and Demand-side Management, since this last one refers to consuming energy at appropriate times (Merkert et. al 2014). The Demand-side Management proposes the turn off of electricity during peak hours to reduce energy consumption and consequently to reduce economic costs, or well. It also proposes an appropriate distribution of charges, spreading the electrical charges of the demand peaks to the valleys. This kind of practices has had an increasing interest in organizations nowadays since what is intended with its application is to distribute the loads so that they may eliminate the need of having their own power plant, considering that its maintenance implies a significant cost. Also it mentions that considering energy consumption and batch setup times within the production scheduling algorithm can reduce energy costs without compromising business productivity.

Considering the constraint due to the setup operations, there are studies such as that conducted by Chen (2009) in which a heuristic method with an apparent - tardiness - cost -with -setup and a nested method to clear the backlog in production scheduling is proposed. Nevertheless it does not include energy efficiency concepts in their analysis.

3. Research Proposal

Some arguments that have to be taken into consideration in the use of clean energy in industry, emphasizes the fact that this economic sector is currently exposed to environmental concerns, more stringent legislation and increased energy costs. San Cristobal (2012) states that the growing interest in environmental issues, dependence on imported fossil fuels and the remarkable arrival of alternative renewable energy, has caused many countries to focus their efforts on proper management of energy resources, especially developed ones that have already started using renewable energy sources. In addition, the transition to a renewable energy comes from two main directions: the global increase in energy demand with the cost of fossil fuels (non-renewable energy) and the downward trend in the process of green energy (Arigliano et al. 2014). With this increase in energy demand, it has exposed the need for unlimited energy sources, i.e., renewable energy, in order to protect and prolong the life of those sources with limited volumes (Zahedi 2011).

An important opportunity of using alternative energy is dictated by Zahedi (2011) where he speaks of a renewable energy distributed generation (RE-DG) which contributes to the overall distribution network of energy. Some of the opportunities obtained are that it can provide an increase in power quality and reliability because more energy is generated by alternative sources. As mentioned above, the energy restrictions (without the use of clean energy) can occur because of a dependency on an energy supplier. Then, when using technologies of distributed generation of renewable energy it is possible to obtain more reliable electricity considering that it produces local energy for users. This idea has a direct impact on the restriction of energy consumption during peak hours, as demand is reduced during this time, considering that the energy source is more local, and minimizes and potentially eliminates congestion energy (Zahedi, 2011). With this, part of the great relevance of the use of clean energy to offset the energy restrictions is denoted; so further study should be given on this topic.

On the other hand, RCPSP models were developed initially for programming production companies that want to work with a lean philosophy. This involves activities and works that must be programmed and are subject to restrictions and resource constraints. Brucker et al. (1999) developed a model of sequencing jobs for companies that work with a modality make to order and must reduce their ability to generate waste of any kind and implement lean methodology. Resources are classified into renewable and non-renewable; those renewable ones are going to have a specific amount in each period of the planning horizon and those non-renewable resources are limited throughout the work horizon.

The original RCPSP pattern had many limitations, such as: 1. it only allows working with renewable and nonrenewable resources separately, 2. only a single task can be performed at the same time, 3. the task and several others could not be interrupted once started. Because of these limitations several authors began to make variations to the model as seen in Hartmann and Briskorn (2008). Ballestín, Valls and Quintanilla (2006) made a model called 1_PRCPSP RCPSP where a maximum of one interrupted task is enabled, this allows that, if a resource runs out or if there are such restrictions that the production plant must stop functions within a period of labor, production scheduling is flexible and can work with this limitation.

The need to include setup times within RCPSP models and restrictions that this could bring regarding the resources, are explained by Mika, Waligóra and Weglarz (2006) where setup times are divided in three ways. First, the ones that only depend on the activity and the resources it needs to be carried out, then the ones that depend on the sequence of activities and resources that were used in the previous activities. Finally, setup times that depend on the occupation of resources by activities throughout the period. This leads to the RCPSP with multiple modes, where setup tasks between two consecutive activities are inserted.

The RCPSP models can be applied to all existing resources in a company. Okubo (2015) implements the way to apply this model to the energy factor and thus schedule the production considering restrictions related with energy consumption during peak hours, contracted demand and energy consumption of setup tasks. As RCPSP originally worked with renewable resources or nonrenewable ones separately, in this article the model with the use of partially renewable resources is studied.

However, researches concerning clean energy in the RCPSP models have not been found. Due to the above, it should be taken into account that, as a result of using renewable energy, the energy restrictions set above can be removed and with it the consequences of these are mitigated in the productivity of the activities.

Energy efficiency is a tool that has been used through the years to counter the effects generated by energy restrictions, however these do not disappear. This article is intended to completely mitigate these restrictions with the use of clean energy sources. However, these type of energy resources also imply new restrictions, as the availability of the resource and its dependence on the amount of supply for energy (wind, tides, sunlight, etc.). Similarly, the effect of these restrictions on production scheduling will be studied to identify the implications in the production due to working with renewable energies.

4. Theoretical Criticism to the Model RCPSP/πRC

The development of the RCPSP models through time and how the authors have shaped them to evaluate the effect of a studied resource under certain restrictions, which limits the use of the resource concerning the production scheduling was mentioned in Section II. Okubo (2015) proposed a model that deals with partially renewable resources and studies the effects that restrictions such as power demand during peak hours and contract demand would have over the production schedule.

This model is known as RCPSP/πRC, and it considers the concept of nodes, which assume that an activity may have different times and resource consumption depending on the mode. It is also proposed to combine resources and in this case the model works with partially renewable resources. Finally this model incorporates the setup operations as a variable of interest and allows the analysis of the implications due to energy constraints. It is important to mention that in the referred paper, renewable resources are those available in a constant amount for each time period, while non-renewable resources are limited during the entire planning horizon.

Okubo (2015) programmed the mentioned model using NP Hard methods and Constraint Programming (CP). Before the formulation of the model, the authors numbered a series of assumptions that are mentioned as follows: (1) Each activity will be processed by a single machine; (2) Each machine can process only one activity at a time; (3) To represent the power consumption during setup operations, setup operations will be included after each activity. This situation is observed in Figure 2. where the activities are denoted as j1 and j2, modes as m1 and m2, the amount of resource (k) consumed as rkjm, the operating time as pkjm and lastly setup operations as pm1m2, representing the setup times between different activities.

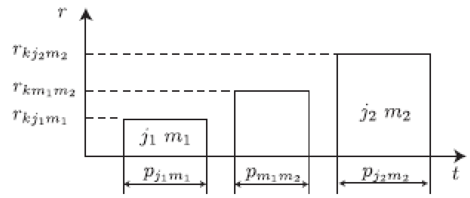

Figure 1. Processing time and resource consumption per activity and setup operations
Source: Project Scheduling Under Partially Renewable Resources (2015)

Demand during peak hours and contracted demand restrictions limit energy consumption throughout the day (Okubo 2015). Companies take actions such as the stoppage of the production during peak hours so that the costs do not rise. Because of this downtime the company must perform the tasks of setup on machines with greater frequency. The third assumption helped evaluate the effect of the increment in setup operations on the total production scheduling and therefore in production times, makespan and work in process.

Nonetheless, this assumption can be removed by working with renewable energy. The setup operations proposed in the RCPSP/ πRC between activities are due to the restrictions of energy that are presented in most industries that cause stoppages during peak hours and due to the contracted demand. Generally, the rate is higher during peak hours so companies prefer to stop production and restart operations after a period, causing more setups.

The third assumption is criticized in this paper due to the fact that by using renewable energy in operations, many of these restrictions could disappear. If clean energy is used, companies do not have to consider stopping production during peak hours due to higher rates or policies imposed because the energy would be provided by the same business (through solar panels for example) or distributed locally, which would cause a considerable reduction in the number of setups performed. According to Mika (2006), setup time is the time necessary to prepare the resources required for processing an activity. Okubo (2015) expresses that setup activities consume a considerable amount of energy. Part of the importance of this review lies in the above due to the fact that constant setups due to stoppages or outages impact both the cost of electricity and the overall process cycle time.

5. Validation of the improvement to the Model

In order to evaluate the model assumptions proposed by Okubo et al. (2015) in their article "Under Project Scheduling Partially Renewable Resources and Resource Consumption During Setup Operations" against the proposal presented in this research, a simulation is done with software Promodel 7.5 to evaluate both cases.

For the existing model, as explained above, one of its assumptions is to perform a setup before each activity. With the proposed model, renewable energy sources will be used to reduce the number of setups that the first one proposes, since they depend only on the availability of the source. Therefore, the proposed model seeks to criticize the assumption of performing a setup before each activity and instead propose a setup only when the power availability of renewable energy is not enough to supply the energy needs of the plant.

Currently, the simulations have been used more frequently to discuss renewable energy systems, because it is a technique that facilitates the analysis of the dynamic behavior of a complex system and setup experiments to test strategies in the system (Kutay, Erhan 2013). For the evaluation of the proposed system a described scenario is presented below for a greater comprehension.

5.1 Case of Study

A production and assembly plant of metal objects in Costa Rica is taken into consideration in this simulation. The production plant area covers about 400 m2 and uses conventional electricity to maintain its operations. The model in which the production schedule is based is the RCPSP / πRC. Model assumptions are taken into account during the simulation. In this case, the situation where you have a setup operation before every activity due to restrictions and the one in which each machine can only perform a single activity are analyzed.

Assumptions take into account in programming:

- The process in which the identity pass through follows the next sequence: oven, injector, miller, drill and lathe. Finally the company reaches a finished product warehouse where the process is finished.

- Working hours are established from 6:00 am - 5:00 pm, which means that the plant stops its operations from 5:00 pm - 6:00 a.m.
- The working days are Monday through Friday.
- An initial setup is performed 30 minutes before starting the workday.
- The processing time of each machine is defined as an N (30, 5) distribution, which means an average time of 30 minutes and a standard deviation of 5 minutes, assuming this is the time it would take the machine to process a batch of 50 units. Therefore, an entity corresponds to a batch of 50 units.
- Only the energy consumption of the machines will be taken into account.
- The simulation runs for one year, from January 1 to December 31.

5.2 Definition of the structure of the current model

First of all, the locations, which correspond to the places where the object of the process is, will be defined. It is establishing that a location corresponds to a machine. Furthermore, each has a capacity of 1 and is programmed so that the simulation will run over a period of one year. The object passing through the locations is called entity and for simulation purposes it is called "nut". In addition, there are locations type buffer, which will serve to establish a temporary storage place before moving on to the next activity. This buffer has infinite capacity and serves as a tail.

To fulfill the assumption that after every activity there is a setup, it is used a downtime type called that is programmed into the process that is executed, after passing through a machine (activity) and lasts for 20 minutes.

5.3 Definition of the structure of the proposed model

The company carries out the installation of solar panels on the roof of the plant to solve its energy consumption with renewable energy and also reduce the amount of idle time due to setup operations. To truly evaluate what solar energy can provide the amount of energy required to operate the plant, one must know the energy consumption of the same. The table below exposes the process machines with their respective energy consumption:

Table 1. Energy requirement of the machines

Machine	Electric Power (KW/h)
Oven	50
Injection	45
Miler	12
Drill	6
Lathe	11
TOTAL	124

The information corresponding to the electricity consumption per machine was provided by Escola Tecnica Superior d'Enginyeries Industial i Aeronatica of Terrassa (2011). It then has a total consumption of 124 kW / h distributed in five machines. It is essential, to assess the feasibility of using solar energy in their company and know the solar radiation in W / m2 generated in the place of location of the production plant; for the case under study, perceived sunlight is required in Costa Rica. This information is tabulated by month and time of day, where radiation data is recorded from 5:00 am to 6:00 pm. This information was taken from the Costa Rica Irradiance Resource Report elaborated by Braya Solar Group and the University of Costa Rica.

For this simulation the same locations and entities are defined and the same production process is simulated. However, when used in this case renewable energy, assuming the existence of a setup after each activity is removed and is only the initial one, which remains to start plant operations and setup that will be executed when solar radiation cannot supply the energy needs of the plant. It should be taken into consideration that although production stoppages caused by restrictions on contracted demand and peak demand hours are eliminated or removed; it should be considered a restriction to regard the variability of the power source. In this case, the source is solar energy, thus the availability of the source will be limited to daylight hours in which there is sun availability and will vary from month to month according to the data mentioned above.

The authors work on the assumption that at the start of the day, electrical energy is used because at that time there would not be enough sunlight to meet the need of 124 kW. Therefore, the simulation is programmed so that if solar energy provided during a certain time of day is enough to supply the energy needs of the plant, then it will have a setup operation for changing electricity to harness renewable resource availability. A new setup will be given in the case that, as the simulation progresses, it detects radiation is not enough, a setup must be made to move renewable energy to electrical energy and thereby ensure the supply of energy to the plant.

To perform the above analysis, a type array table is used, where all data from solar radiation per hour per month is contained. If the total energy needs of the production plant are 124 kW, programming will detect when an entity leaves the machine site (instead of performing a setup as above) and check for availability. If so, then a shift to renewable energy is generated, and otherwise continues using electricity. This review is done every time an entity goes through an activity performing the necessary setups. A downtime type called is used for programming of possible setups (one ignition and one shutdown of the renewable energy source).

6. Analysis of Results

In the presented case, the down percentage turns out to be the most important indicator to consider, as this refers to the time the process was stopped due to the operations of setup and this is precisely the intended effect that is planned to decrease with the proposed model. The comparison of the RCPSP/πRC model results and those obtained with the proposed model are compared as follows. In Table 2 the utilization rate of the machine is expressed for both models. In this case, the results for the proposed model has percentages ranging between 96.16% to 97.23% which represents an average increase of 14% compared to the model RCPSP / πRC. The following is a summary of the above situation:

Table 2. Machine Utilization Percentage

% Utilization			
Machine	RCPSP/ πRC model	Proposed model	Gap
Oven	83.57	97.23	13.66
Injector	81.64	96.23	14.59
Milling Machine	81.36	96.29	14.93
Drill	82.03	96.19	14.16
Lathe	80.61	96.16	15.55

Table 3. Down Percentages

Down Percentage			
Machine	RCPSP/ πRC Model	Proposed Model	Gap
Oven	15.91%	2.24%	13.67%
Injector	17.75%	1.45%	16.30%
Milling Machine	18.01%	1.48%	16.53%
Drill	17.18%	1.41%	15.77%
Lathe	18.43%	1.49%	16.94%

Based on these data, a graphic is prepare to visualize the information:

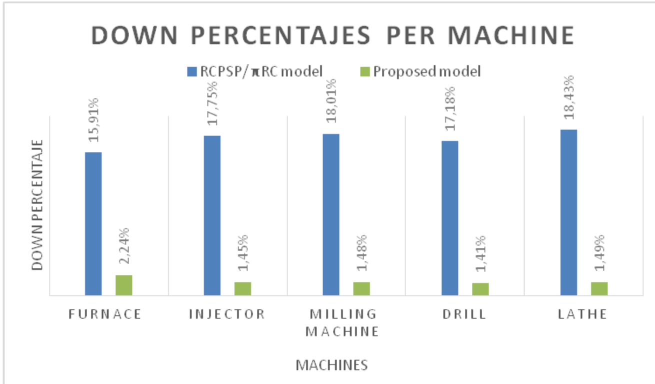

Figure 2. Results Comparisons
Source: The Authors (2015).

From the information provided by Table 3 and Figure 2, it is possible to verify that the implementation of the proposed method achieved a significant reduction in setup times. This reduction is reflected positively on reducing cycle time which may allow the organization to increase productivity.

To supplement this information, the utilization rates of the machine are compared. In the first scenario of the RCPSP/πRC model, the percentages vary between 80.61% and 83.67%. The proposed model achieved a significant reduction in the setup times, this reduction suggests that this time that was saved can be used in other operations or other activities that will improve the quality of the product. Table 2 shows that the percentages of machine used for the proposed model results in a value ranging between 96.16 % and 97.23 %, which confirms the above situation.

Besides the providing Promodel results previously observed, an array type export is created with the simulation; the system sends the time when a setup occurs and is based on a binary system (0.1) to define whether the setup was to migrate from renewable energy to electric or vice versa. If the process needs electrical power to work the system types a 0. If not the system will type 1.

In our Simulation Framework, many 0 or 1 are presented depending on what the system read. In addition, the exact minutes in which a setup operation was performed is provided and the difference between setups so it would be easier to recognize how long renewable energy or conventional energy is used.

In the proposed case, it is observed that using renewable energy within an established working day, the number of operations of setup, because of energy restrictions, would be reduced by between 13% and 17%, which means that this time can be fully invested in the process of adding value to the final product, or it could mean a reduction in the cycle time which could increase the percentage of throughput. When comparing the utilization rates of both models it is verified that, with the proposed model in this research, percentages of resources utilization are all above 96%.

7. Conclusions

In the implementation of renewable energies in companies, benefits are usually seen mainly in the environmental, social and economic areas, yet their exploitation at the operational level have not been highly discussed.

Most authors identify a problem in dependence on suppliers of electricity and energy constraints. To solve the above, in most cases the energy efficiency is used. Energy efficiency does not eliminate the root problem but it´s designed to produce solutions to these restrictions involved. No advantage involved in the use of renewable energies that eliminates this dependence supplier of electricity and energy restrictions are observed.

In many cases, for seeking energy-efficiency, it is recommended production stoppages at times of peak or because it is coming at a high utilization of energy power that will affect payment for contracted demand. These strikes are observed in the model RCPSP/πRC, which add a setup task after each activity to illustrate the energy implications.

In this scientific paper, the main research was questioning the assumption of adding setup operations after each activity, by stating that by using renewables, needed downtime or outages are removed. However, as clean energy is an intermittent energy, other restrictions affecting setups due to the availability of the same are introduced. To check the impact on production operations with the situations set out above, a simulation program through

ProModel version 7.5 was made. With the use of renewable energy in the study case presented, a significant reduction in the time spent on setup operations can be achieved and therefore a decrease in the cycle time.

When performing the simulation software, it is observed that the use of renewable energy as the solar energy, include a restriction that corresponds to the dependence of the availability. However, if it has enough availability as in current case, in Costa Rica, the company could rely for a significant time of that energy. Note that this may vary from country to country and also on the type of renewable energy used.

With the exposed results, it can be verified that with the use of renewable energy to meet the energy needs of a production plant similar to those stipulated in the case study characteristics, you can achieve a significant reduction in the time spent to setup operations and therefore a decrease in the cycle time.

8. Future Lines of Research

In the simulation, the study case was executed using solar energy as the renewable type of energy, this because thanks to the environmental properties of Costa Rica, solar energy is a powerful source. Also the government legislation promotes the use of solar panels and photovoltaic installations. Nonetheless as a future line of research it is proposed to simulate the situations using a different kind of renewable energy such as biomass or wind power.

This article contains simulations done by means of installed software with student licenses obtained by the University of Costa Rica. The RCPSP models work under software programming NP-Hard, CP (Constraints Programming) and IP (Integer Programming). So, for future research it is proposed to carry out a mathematical model using the programming NP-Hard to observe the behavior of the production scheduling with common programming of RCPSP models.

Moreover, as the proposal is purely focused on the operational level of the usage of renewable energy, the implications in economic terms can be studied for future research. This add-in model would allow a thorough overall comparison, in monetary terms, of the installation, use and impact on the manufacturing process by using clean energy versus energy based on fossil fuels, all this in order for it could be easy for a company to make the decision of choosing to be provided by any of these two types of energy in their production processes.

Furthermore, a proposed research is to examine the energy consumption besides the machine consumption, to determine if renewable energies can supply the entire firm electrical needs and to identify that the consumption is not only due to the machines usage.

References

Ambec, S., Crampes C., Electricity provision with intermittent source of Energy, Resource and Energy Economics, nº 34, pp. 319-336, 2010.

Arigliano A, Caricato P, Grieco A, Guerriero E., "Producing, storing, using and selling renewable energy: The best mix for the small medium industry," Computers in Industry, vol. 65, no. 3, pp. 408-418, 2014.

Artigues C., Lopez P., Haït A., Scheduling under energy constraints, Hal archives-ouverts, 2009.

Ballestín F., Valls V., Quintanilla S., Pre-emption in resource-constrained project scheduling Ballestín, Valls y Quintanilla, European Journal of Operational Research, vol. 189, pp. 1136-115, 2006.

Baratta A., Renewable Energy: Status and Prospects – Status of Electricity Generation from Renewable Energy, Global Climate Change - The Technology Challenge, ch. 5, pp. 157-189, 2011.

Beerbuhl S., Frohling M., Schultmann F., Combined scheduling and capacitu planning of electricity-based ammonia production to integrate renewable energies, European Journal of Operation Research, 2014.

Brucker P., Drexl A., Möhring R., Neumann K., Pesch E., Resource Constrained Project Scheduling Notation, Classification, Models, and Methods, European Journal of Operational Research, vol. 112, pp. 3-41,1999.

Chen Y.F., Scheduling on unrelated parallel machines with sequence- and machine-dependent setup times and due-date constrains, Int J Adv Manuf Technol, nº 44, pp. 1204-1212, 2009.

Delucchi M., Jacobson M., Meeting the world's energy needs entirely with wind, water and solar power, Bulletin of the Atomic Scientists, pp. 34-39, 2013.

Du Y., Yi Q., Li C., Liao L., Life Cycle oriented low-carbon operation models of machinery manufacturing industry, Journal of Cleaner Production, 2014.

Escola Tecnica Superior d'Enginyeries Industial i Aeronatica de Terrassa. Estudio de implantación de una industria de motores de naja tensión ubicada en Catalunya. Available: http://upcommons.upc.edu/pfc/bitstream/2099.1/13767/2/ANEXO%20I%20-%20Picarolia%20-%20Fichas%20de%20m%C3%A1quinas.pdf, 2011.

Fang K., Lin B., Parallel-machine scheduling to minimize tardiness penalty and power cost, Computers and Industrial Engineering, nº 64, pp. 224-234, 2012.
Fysikopoulos A., Pastras G., Alexopoulos T., Chryssolouris G., On a generalized approach to manufacturing energy, Int. J Adv Manuf Technol, n° 73, pp. 1437-1452, 2014.
Hartmann S., Briskorn D., A survey of variants and extensions of the resource-constrained project scheduling problem, European Journal of Operational Research, nº 207, pp. 1-14, 2014.
Hopp, W., Spearman, L. Factory Physics. New York: Irwin/McGraw-Hill, 2014.
International Energy Agency, Worldwide Trends in Energy Use and Efficiency, 2008.
Kutay H., Erhan C., Simulation and Renewable Energy Systems", in Assessment and Simulation Tools for Sustainable Energy Systems, ch.15, pp. 311-331, 2013.
Merkert L., Harjunkoski I., Isaksson A., Säynervirta S., Saarela A., Sand G., Scheduling and energy - Industrial challenges and opportunities, Computers and Chemical Engineering, nº 72, pp. 183-198, 2014.
Mika M., Waligóra G., Weglarz J., Tabu search for multi-mode resource-constrained project scheduling with schedule- dependent setup times, European Journal od Operational Research, nº 187, pp. 1238-1250, 2006.
Mourshed M., Pitfalls of oil-based expansion of electricity generation in a developing context, Energy Strategy Reviews, nº 1, pp. 205-2010, 2012.
Okubo H., Miyamoto T., Yoshida S., Mori K., Kitamura S., Izui Y., Project Scheduling Under Partially Renewable Resources, Computers & Industrial Engineering, nº 83, pp. 91-99, 2015.
San Cristóbal J.R., The Renewable Energy Industry and the Need for a Multi-Criteria Analysis, Multi Criteria Analysis in the Renewable Energy Industry, ch. 1, pp. 1-5, 2012.
Schmid S.R., Energy Consumption in Manufacturing, The 4th Manufacturing Engineering Society International Conference, Notre Dame, IN, USA, 2012.
Trentesaux D., Prabhu V., Sustainability in Manufacturing Operations Scheduling: Stakes, Approaches and Trends, Advances in Production Management Systems. Innovative and Knowledge-Based Production Management in a Global-Local World, pp. 106-113, 2014.
Vinh C., Khiang C., Peen O., Min X., Hong D., Luo M., Leng H., Lewis F., Classification of energy consumption patterns for energy audit and machine scheduling in industrial manufacturing systems, Transactions of the institute of Measurement and Control, pp. 583-592, 2012.
Wang X., Ding H., Qiu M., Dong J., A low-carbon Production Scheduling System Considering Renewable Energy, IEEE Transl. IBM Research, Beijing, China, 2011.
Yang M., Yu X., Energy Efficiency: Benefits for Enviroment and Society, Londres: Springer, pp. 1-11, 2015.
Zahedi A., A review of drivers, benefits, and challenges in integrating renewable energy sources into electricity grid, Renewable & Sustainable Energy Reviews, vol. 15, no. 9, pp. 4475-4479, 2011.

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