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APPLICATION OF RESOURCE EFFICIENT AND CLEANER PRODUCTION THROUGH BEST MANAGEMENT PRACTICE IN A PALLET MANUFACTURER SAWMILL LOCATED IN THE CITY OF PUYO-ECUADOR

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ABSTRACT

Resource Efficiency and Cleaner Production strategies were implemented in a pallet manufacturer sawmill in order to observe their effect on productivity and the environment. The main goal was to inform Small and Medium Enterprises the advantages of a sustainable and green production and to encourage them to invest in Resource Efficiency and Cleaner Production strategies. In the context of Resource Efficiency and Cleaner Production, the Best Management Practices are the first low cost and easy to apply measures to transform the current industrial system into a more sustainable and green industrial system. A longitudinal research approach was used. The investigation was performed in three phases: diagnosis, selection of measures to overcome the identified problems, and implementation and evaluation of results. Once the wood companies' diagnostic data was collected for three months, surveys were conducted with the managers and workers of "Maderol" which served as a pilot sawmill where the Best Management Practices were applied. A survey with closed yes/no-questions and a non-structured interview were conducted. Based on this information, Best Management Practices measures were identified and implemented for a test period of three months. Results were analyzed based on the economic data of the sawmill and a second survey after the test period. The results obtained from our study on a pallet manufacturer sawmill located in the city of Puyo-Ecuador confirm that the Best Management Practices can provide clear and specific guidance to Small and Medium Enterprises so that they can quickly improve their production efficiency and reduce their negative impact on the environment.

Keywords: Efficiency, optimization, productivity, small medium business, waste reduction.

INTRODUCTION

According to the Brundtland Commissionreport (1987), the excessive use of natural resources led to damage to the environment and our quality of life. To counter this problem, in 1990 the United Nations Environment Program (UNEP 1990) for the first time defined the term Cleaner Production (CP) to promote the transition towards a more sustainable industrial system and Green Industry. The concept of CP includes the continuous application of an integrated environmental strategy for processes, products, and services to increase efficiency and reduce risks to humans and the environment. However, due to the global economic and environmental crisis together with the growing consumer awareness and legislative pressure of the last decades, the United Nations Industrial Development Organization (UNIDO) together with the UNEP broadened the definition of CP and included the concept of resource efficiency (RE) which is the key element of the transition towards a sustainable industrial production (Matos *et al.* 2018).

Resource Efficient and Cleaner Production RECP) entails three sustainability goals: a) increase of the competitiveness through optimization of the use of raw material and reduction of the water and energy consumption (Bermudez-Garcia 2017), b) environmental protection by minimizing the adverse impact of the

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industry on the natural environment, and c) social enhancement by providing jobs and protecting the wellbeing of workers (UNIDO 2016). In practical terms, RECP aims to produce more goods with fewer resources, with minimal negative effects on people and the environment (Vieira and Amaral 2016), thus reducing or eliminating waste and contaminants right at the source and not treating them after they have been generated (Fúquete-Retamoso 2007, Hoof *et al.* 2007).

The implementation of RECP in an industry or organization follows a step-wise methodology that can be summarized in five main steps: 1) Estimation of resource use and waste and emission generation; b) Source and cause analysis; 3) Identification of possible strategies; 4) Implementation of selected strategies; and 5) Follow-up and continued work (Lindhqvist 2013). In general, the RECP strategies described below can be gradually adopted according to the requirements of the industry:

- Best Management Practices (BMPs), which are preventive measures focused on preventing loss of supplies and resources, minimizing waste, saving water and energy, enhancing business competitiveness (Granada 2007), and improving the work conditions and security of the workers (Prévez and Sánchez-Osuna 2007). BMPs also aim to rationalize, decrease, reuse, and recycle the materials, as well as, create social awareness which has a positive impact on business (ONU 2002).
- Change of the current input materials for more environmentally friendly ones.
- Better process control: Modification of the procedures and minimization of the resource consumption and the generation of waste and emissions.
- Equipment modifications and acquisition of new equipment.

Nowadays, the implementation of RECP is considered a social responsibility as on the one hand it focuses on environmental management and on the other hand aims at a continuous improvement of the product (Alaña-Castillo *et al.* 2017). Nevertheless, the implementation of the above strategies in Small and Medium Enterprises (SMEs) is difficult because they lack knowledge about the RECP concept and new technologies. Also, Zhou and Zhao (2016) mentioned that the SMEs owners often see climate change as an abstract problem that does not affect them and that they are not directly responsible for environmental issues. Furthermore, the lack of capital for research and innovation, and the lack or absence of "green" credits for environmental projects also limits the implementation of RECP (Bernal *et al.* 2016, Vieira and Amaral 2016). To overcome these barriers, Klewitz and Hansen (2014), who analyzed the strategic sustainability behaviors of SMEs between 1987 and 2010, concluded that interaction with external actors (e.g. customers, authorities, research institutes) is an essential part to achieve a sustainable development of SMEs. Another important aspect to support the transition is to foster a "green" company culture among staff and managers (Rizos *et al.* 2016).

Despite the barriers, some research works have been made to demonstrate the benefits of RECP. For example, Henriques and Catarino (2015) implemented the Sustainable Value concept in 19 different SMEs within Portugal. They proved the benefits concerning the reduction of inputs (water, energy, and materials), as well as, emissions and waste reduction. Likewise, several authors have also developed proposals however without showing the effects of their implementation. For instance, Prévez and Sánchez-Osuna (2007) developed a manual to apply RECP in the citrus sector of Havana; and Semanate (2017) proposed a plan to implement CP to reduce the consumption of water in the cheese production process of a dairy processing company; and Garcia (2016) proposed a clean technology approach to reduce the wood waste in an industry in Peru. Equally, Sánchez-Paucar (2013) elaborated an improvement plan based on RECP to enhance the environmental quality in the city of Quito-Ecuador. In this work, we are not only proposing a strategy for RECP, but are also showing its implementation and assessing the results in short term. Short-term results are of special interest since SMEs need a tested and inexpensive alternative that generates tangible economic and environmental benefits in the short term to stimulate the manager and staff to become a green and sustainable industry.

This work aims to encourage the implementation of RECP in the logging SMEs in the Amazon region of Ecuador, where a poor transfer of technology, lack of infrastructure and knowledge of environmental laws and regulations lead to a deficiency in the logging process (Gobierno Autónomo Descentralizado Provincial De Pastaza 2011). Less than 2% of industries apply waste handling policies in order to protect the environment, and only 4% of companies invest in staff training (Gobierno Autónomo Descentralizado Provincial De Pastaza, 2011). Therefore, these negative aspects produce adverse effects on the environment, worker health and produce economic downfall.

In the city of Puyo, (Pastaza province - Ecuador) there are seven sawmills that use “Pigüe” (Pollalesta Karstenni) as raw material. Six are primary industries that transform wood into planks and boards for sale, and one is both a primary and secondary mill which transforms wood into planks and boards and uses them to manufacture pallets. This investigation is first focused on performing a short analysis of the productivity index of the six primary industries and doing an extensive analysis of the production process of the secondary sawmill called Maderol. The purpose of the analysis is to identify the causes that affect profit by calculating the economic cost that represents waste and determining the efficiency of the process.

After identifying the actual situation of the seven sawmills, the secondary industry, Maderol is chosen as a pilot production plant to implement and test the effectiveness of RECP but only through Best Management Practices as these SMEs do not have the necessary economic capital to invest in new technology and machinery, and BMPs are low cost and simple implementation measures, with high potential savings (Bermudez-Garcia 2017, Floría 1999, Lindhqvist 2013).

METHODS

This work follows a longitudinal research approach (Hernández *et al.* 2014) so we performed our investigation in three phases, a first phase of diagnosis, a second phase of selection of measures to overcome the problems, and the last phase of implementation and evaluation of results. The first phase used a non-experimental-transactional method to describe the actual situation of the seven sawmills in the city of Puyo during September, October, and November 2013. The information about the production process was obtained using non-structured interviews and conversations with the managers and employees, as well as, the direct observation of the sawmills.

For the six primary sawmills, a productivity index based on labor, electricity, and waste costs was calculated using the following Equation 1:

$$Productivity\ Index = \frac{Total\ sale\ in\ USD}{\left(labor\ cost + electricity\ cost + waste\ cost\right) in\ \ USD} \qquad (1)$$

In Equation 1 the waste cost is the multiplication of the unit cost of logs and the difference between the volume of the logs and the rough lumber. The number of logs of wood bought was taken from the transportation documents issued by the Ministry of Environment Ecuador (MAE). The owner of each sawmill supplied the data corresponding to the total amount of rough lumber that was sold, as well as the labor cost. The electricity consumption cost is the sum of the 3 monthly reports of the Puyo Electric Company.

For the secondary industry Maderol, an exhaustive analysis of the current situation was made. First, we made an internal audit to identify the variables of the process and used Eco-maps to localize the potential hazards related to energy, waste, and problems with neighbors (e.g. noise). In addition, 2 types of surveys were applied, one to the manager and another to the workers, with 15 and 12 questions respectively. The survey with Closed-Ended Questions, YES-NO questions, was focused on 5 topics: 1. waste generation, 2 electrical energy consumption, 3. industrial safety, cleaning, and maintenance, and 5. Knowledge of RECP and BMPs. At the end of the first phase, all the information was used to determine the monthly management indicators (Table 1) suggested by Beltrán (2000) to assess the waste generation, energy consumption, and productivity of the SMEs. They are fundamental tools for the monitoring and follow-up in the implementation of RECP as they are quantitative measures that allow to identify the trend or changes in the variables of the productive system with respect to time in order to alert about problems and take measures to solve them.

Table 1: Management Indicators.

Aspect to assess	Indicator	Purpose
WASTE GENERATION		
Efficiency of raw material (%)	Percentage of the finished lumber compared to the logs of wood bought	To know the percentage of wood that is not part of the final product.
Wood Waste (m^3)	Difference between logs of wood bought and finished lumber	
Percentage of Wood waste (%)	Percentage of wood waste compared with logs of wood bought	
Wood Waste cost (USD)	Multiplication between the Wood waste in m^3 and the unit cost of logs in USD/m^3	
ENERGY CONSUMPTION		
Consumed electric energy (kWh)	kWh recorded in the report of the electric company	To determine the energy consumption associated with the production of the finished lumber.
Electricity cost (USD)	Monthly cost paid to the electric company	
Electricity consumption for finished product (kWh/m^3)	Consumed electric energy in kWh divided by Finished lumber in m^3	
Relative energy saving (%)	Difference in electricity consumption during the current month and the last month, and then, this result is compared with the energy consumption of the last month.	
PRODUCTIVITY		
Productivity of labor index	Rate between total sales of pallets and the labor cost	To measure the effectiveness of the resources used in the production process.
Productivity of raw material index	Rate between total sales of pallets and cost of raw material	
Total productivity index	Rate between total sales of pallets and total operative cost. The total operative cost is the sum of raw material cost, electricity cost, indirect cost, depreciation of equipment and wood waste cost.	

Furthermore, to determine the environmental impact of the process, the footprints indicator was calculated. The footprint identifies the amount of total Greenhouses Gases (GHG) emitted into the atmosphere due to the productivity activity (OECC 2016). In this research, we only took into account the indirect GHG related to electricity consumption and used 341,20 g CO_2 kWh^{-1} for 2013 and 342,6 g CO_2 kWh^{-1} for 2014, values taken from (Narváez 2015).

After establishing the real situation of the seven sawmills and identifying the problem areas in the Maderol sawmill, the second phase started. We elaborated a guide of Best Management Practices to solve the problems. The BMPs guide was implemented only in Maderol because it has the most complete production process of the analyzed group. Then, Maderol, an SME with one manager and 25 employees, was our pilot sawmill to test if BPMs raise incomes through improving the manufacturing process, reducing the waste and production cost, as well as, reduce the environmental impact and risk for workers.

For the last phase, the results of the BMPs implementation were monitored for 3 months: December 2013, January 2014, and February 2014. After the changes, the new information related to waste generation, energy consumption, production efficiency, and environmental impact were compared to the values of the first diagnostic, using the management indicators previously defined in Table 1. In the same way, the surveys of the first phase were repeated to gauge worker awareness and satisfaction about the new BMP measures.

Furthermore, to validate our hypothesis: "BPMs are positively received by employees and improve working conditions", we chose two yes/no questions, one about the acceptance of the benefits of the implementation of BPMs and the possibilities of more investment in them, directed to the manager, and the second one about the appreciation of risk reduction in the sawmill directed to the employees. The results of these two questions were analyzed with the Chi-squared test that is a nonparametric statistic test useful for qualitative variables with a sample size less than 30, according to Iglesias (2012). Consequently, the observed frequency (*fo*) of YES or NO answers corresponding to the two question were organized in a table of double-entry called 2x2 contingency table. Next, the expected frequency (*fe*) for every option of the table was calculated using the following Equation 2:

$$fe = \frac{(Row\,marginal\,total)*(Column\,marginal\,total)}{Grand\,total} \quad (2)$$

and the Chi-squared value for every option was evaluated with Equation 3:

$$X_c^2 = \sum \frac{(fo - fe)^2}{fe} \quad (3)$$

where the subscript “c” are the degrees of freedom, in this case 1, which was determined as Equation 4:

$$c = (number\ of\ rows - 1)(number\ of\ columns - 1) \quad (4)$$

Finally, we compared the sum of all the Chi-squared values with the critical theoretical value of Chi-squared (X_t^2);6,63 that pertains to one degree of freedom with a significance level (α) of 0,01 and a confidence interval of 0,9. Hence, if $X_c^2 > X_t^2$, the hypothesis is accepted as true, opposite case, the hypothesis is considered null or false.

RESULTS AND DISCUSSION

Primary sawmills

The information gathered from the 6 primary sawmills during the diagnostic period of September to November 2013 is summarized in Table 2. In all sawmills, the estimate of the efficiency of the raw material is around 40%, so waste was almost 60%. This value is excessive from what is defined by MAE in the Forest Harvesting System (SAF), which considers that waste in sawmills should be between 40% and 45%. The average economic cost of the waste was a little more than 25000 USD for the three months, and the cost of electricity was around 1200 USD which affect the profitability of every sawmill and represent a high operative cost compared to their production.

Table 2: Information from the 6 primary sawmills located in the city of Puyo.

Nº	Sawmill	Rough lumber (3^M)	Finished lumber			Wood waste		Electricity		Labor cost (USD)	Productivity Index
			Vol. (3^M)	Sale (USD)	Effic. (%)	Vol. (3^M)	Cost (USD)	kWh	Cost (USD)		
1	Colon Salazar	1874	805	28175	43%	1069	28863	12302	1107	2880	**0,86**
2	Manuel Gomez	1767	775	27125	44%	992	25792	12959	1166	2880	**0,91**
3	Inés Salazar	1845	779	27265	42%	1066	28782	12844	1156	2880	**0,83**
4	Lourdes Briones	1601	649	22715	41%	952	27608	11180	1006	2880	**0,72**
5	Angel Medina	1340	517	18095	39%	823	23044	12870	1158	2880	**0,67**
6	Branger Martínez	1252	462	16156	37%	790	21330	14258	1283	2880	**0,63**

Furthermore, from interviews with the managers and direct observation of the sawmills, we identified that the machinery is obsolete. Most workers are not well trained to process the wood. The inventories of raw materials are not supervised, and the workers are not aware of the waste of energy. Inevitably, these factors lead to a low average productivity index of 0,80 in the primary sawmills analyzed.

Maderol sawmill

Maderol is a secondary SME that manufactures and sells two types of pallets: American (102cm x 122cm) and European (100cm x 120cm) which are produced following a sequential process. First, the logs of wood are bought on the forest roads where they are stacked in standard columns of 1,6m. At the time of purchase, the data about the origin, species, and volume is written on the "Transportation log" issued by are presentative of the Ministry of Environment Ecuador (MAE) that permits the mobilization of wood. Afterward, the logs are stacked on trucks and the real volume is calculated. The real volume is obtained by multiplying the total volume of wood accommodated in the truck by a spacing factor of 0,78 which compensates for empty spaces between the logs. Then, the logs are transported to the sawmill and are placed at an outer area of the sawmill to start the sawing process. First, the logs are debarked using a rotatory machine with a diesel engine. Second, the logs are classified as thick and thin, but no additional quality control is performed. The thick pieces are used for boards and the thin ones for strips and blocks. Third, the logs are broken into cants (four-sided lumber) with an electric head rig saw. Forth, all irregular edges of the cants are trimmed off with an electric edging. Fifth, using an electric saw the ends are cut according to the lengths required and with a trimmer the cants are trimmed into 4 or 6 boards of 2 cm each. If the boards need to be beveled, the boards enter the electric bevel to remove the edges at one end. Additionally, if the wood is used to manufacture European pallets, some cants are divided into blocks (12,5 x 9 x 9) cm. Finally, the pallets are built using the pre-manufactured boards, strips, and blocks. The waste from the whole process are barks, sawdust, small pieces of lumber, and thick and thin chips. The production is frequently stopped for machinery failures, in particular dull blades that also increase the amount of waste.

Moreover, the information collected by the internal audit and the Eco-map tool allowed to identify and localize the problems in the five areas of Maderol: office, storage area, sawmill, open area, and collection area, as shown in Figure 1. We observed that the first three areas consume electricity for light and the major consumption is caused by the machines of the sawmill. The workers do not disconnect the machines after use as the connections are in bad condition and workers fear electrocution. All the areas, except for the office, are unsafe and dirty and have waste accumulated. Normally, the employees worked without any personal protective equipment, so they were exposed to cuts, blows, burns, respiratory problems, etc. The waste was removed from the workplaces every two or three days and then accumulated outside the sawmill to be burned later. There was no recycling concept. Furthermore, Maderol is placed in the urban area of Puyo, so its industrial activity also affects the neighbors, primary with machine noise, sawdust that clogs the sewers, and the smoke produced from burning waste.

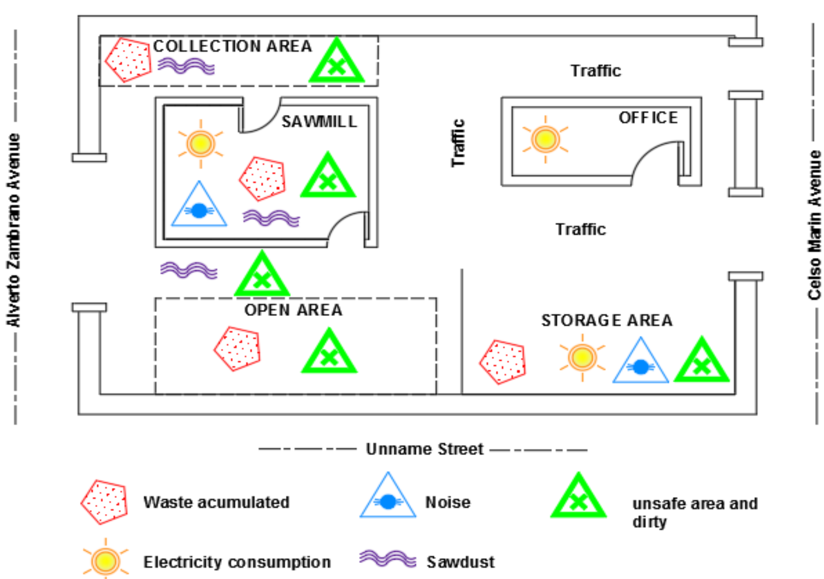

Figure 1: Eco-map of the Maderol sawmill indicating waste accumulation, noise, unsafe and dirty areas, sawdust and electricity consumption.

Manager survey results

The manager mentioned that usually the number of logs necessary to manufacture the finished lumber is based on experience only. Furthermore, there is no quality control, no record keeping of the raw material, no supervision in the production process, and no procedure to decrease waste material. Consequently, he does not know the amount of waste generated or how much it costs. In addition, he mentioned that the process is inefficient since the machines are old and do not receive preventive maintenance and changing them would be very expensive and impossible at this moment. Regarding the employees, he told that the sawmill does not supply them with personal preventive equipment, and that they do not receive any training prior to being hired, and that they are not responsible for keeping their workspaces clean every day. Finally, he wants to apply BMPs to improve the profitability of his SME if these measures have a low cost.

Employees survey result

The 25 employees surveyed state that the machines are obsolete, and 96% of them do not clean their workplace and tools. 60% of the workers have had an accident and only 8% think that the sawmill complies with regulations to avoid occupational hazards. 100% of them have not received personal safety equipment, 100% of them believe that the waste is excessive. 100% answered that they do not disconnect the machines after completing their task. Finally, all the 25 workers comment that they do not know the RECP-BMPs concept, but they would be willing to apply them if BMPs improves labor conditions.

Guide of best management practice

After analyzing all causes of the problems in the sawmill Maderol, a guide to Best Management Practice was developed. This BMPs guide was divided into 4 blocks with the aim to reduce waste, decrease energy consumption, provide safety to the employees, and improve the maintenance of the machinery and cleaning of the workplace. The cost of the BMPs represented only 2% of the total sales of the period of implementation. The details of the measures and costs are summarized in Table 3. To improve the production efficiency, the bought logs were inspected and classified according to their shape, straightness, and fungus or insects' attacks into three categories. First class: cylindrical, straight and minimum attacks. Second class: semi-cylindrical, semi sinuous and with a 30% maximum of attacks. Third class: irregular shape, crooked, and high level of attacks. The first and second class were used in the production process and the third class was returned to the supplier. Two workers performed the preventive maintenance of machines every first Saturday of the month outside of the workdays. They checked the state of blades, rollers, machine head, etc., of the rotatory machine. Furthermore, the workers were relocated according to their experience and skills. For instance, the most experienced ones to sort out the logs and to operate the machinery, or the agilest ones to dispatch the pallets.

Table 3: Guide of Best Management Practices.

Best Management Measure	**Cost (USD)**
1. WASTE REDUCTION	
1.1. Reception and classification of logs bought per quality.	0,00
1.2. Inspection of logs before the sawing process.	0,00
1.3. Recycling of the waste material.	22,00
1.4. Training and supervising of employees.	90,00
2. ELECTRIC ENERGY CONSUMPTION	
2.1. Replace defective electrical connections to guarantee proper machinery operation.	400,00
2.2. Train staff on the efficient use of electrical energy to decrease electrical consumption.	90,00
3. OCCUPATIONAL SAFETY AND HEALTH	
3.1. Supply personal protection equipment to avoid accidents and injuries to workers.	1417,00
3.2. Creation of Emergency procedures.	0,00
4. MAINTENANCE AND CLEANING	
4.1. Store tools and equipment properly.	0,00
4.2. Daily cleaning of workplaces to lessen the amount of sawdust emission and noise.	68,00
4.3. Employees training and supervising.	90,00
4.4. Carry out monthly maintenance for all machinery (sharpening the blades and adjusting accuracy) to reduce waste associated with machine failure.	300,00
TOTAL COST BMPs (USD)	2477,00

The personal preventive equipment also helped to increase the efficiency, because the number of small accidents (e.g. scratches) that stopped the production decreased by 13%. Besides, the feeling that the company takes care of the employees encouraged them to produce more in less time and save resources. The machinery was also relocated so that the employees can work more comfortably and avoid dangerous situations. Another important point was the training of the workers and the manager regarding the efficient use of resources, machinery handling, first aid, occupational hazards, and workplace cleanliness.

To reduce the energy consumption, all the deteriorated electrical connections were replaced by new insolate cables and standardized plugs. Additionally, protections against short circuits were added to all electrical manual machines. Furthermore, the manager and the staff received training on the efficient use of electrical energy which generated awareness about the energy consumption.

The recollection of waste was made every day after work by the employees. They put the waste in bags or closed containers to avoid particles of sawdust in the environment that affect the respiratory system, or trips or slips due to the bigger waste. To sum up, the waste (chips, sawdust, pieces of wood) was sold to other industries that use it for charcoal production, or to manufacture fruit crates.

Management indexes

Table 4 presents information related to production and costs during the three months of diagnostic and the 3 months using the BMPS. The amount of raw material bought in both periods is similar, but the quantity of waste was reduced from 260 to 207 cubic meters. Another aspect observed was the decrease in labor cost to half the initial cost due to an increased productivity, although the total operative cost apparently remains constant. In addition, the most important change was the average of the sales, which in the last period with BMPS achieved approximately 1,5 times the quantity of the diagnostic period. Maderol could now cover the unsatisfied demand on the market that before could not be covered due to problems with the machines or the absence of the workers for health reasons. Consequently, the average profits increased notably from around $3400 dollars in September to November to almost $20000 dollars in December to February.

Table 4: Production and economic parameters of Maderol before and after implementation of BMPs.

Production and Economic parameters	Before			After		
	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14
Logs bought (m^3)	417,00	342,00	416,00	488,00	423,00	413,00
Finished lumber (m^3)	127,57	111,48	157,79	258,50	222,46	219,99
Wood waste (m^3)	289,43	230,52	258,21	229,50	200,54	193,01
Consumed electric energy (kWh)	385,74	412,02	471,87	431,01	389,25	348,84
Raw materials cost ($)	5475,46	4390,57	8013,50	10410,46	7497,78	7428,71
Electricity cost ($)	1157,22	1236,06	1415,61	1293,03	1167,75	1046,52
Indirect cost ($)	3003,00	2844,00	3225,00	3254,00	2844,00	2811,00
Labor cost ($)	2080,00	1680,00	1680,00	960,00	960,00	960,00
Depreciation ($)	0,00	0,00	0,00	0,00	0,00	0,00
Wood waste cost ($)	8104,04	6454,43	7230,00	6426,04	5615,22	5404,29
Total operative cost ($)	19819,72	16605,06	21564,11	22343,53	18084,75	17650,52
Total sales ($)	21460,00	19212,50	27332,50	43717,50	37555,00	37482,50
Total Profit ($)	1640,28	2607,44	5768,39	21373,97	19470,25	19831,98

Before the BMPs implementation, the efficiency of the raw material (Figure 2) was between 30% to 35% and the amount of waste approximately 65% which exceeded the limit allowed by MAE and generated an average productivity index of the raw material of 4, due to inexistent supervision of the process and the lack of training of the workers. Consequently, with the first block of measures focused on waste reduction and maintenance of the machines, the productivity index of the raw material increased to 4,2 and stabilized at 5. Using BMPs, the quantity of finished lumber was 53% of the raw materials which is inside the recommended limits for the efficiency of the raw material.

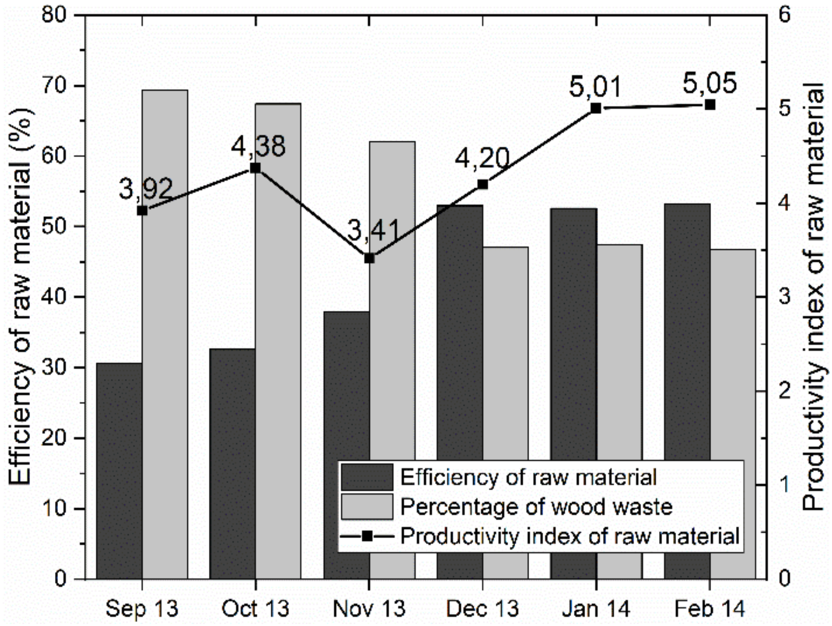

Figure 2: Management Index related to the use of Raw material.

The analysis of the electric energy consumption and the Carbon footprints shown in Figure 3 allowed us to identify that Maderol used an average of 3,25kWh per cubic meter of finished lumber which produced between 131 to 161 kg CO2eq. By replacing defective electrical connections and training staff, the electrical energy consumption was reduced by half per cubic meter and obviously, also the carbon footprint (kgCO2eq) was reduced.

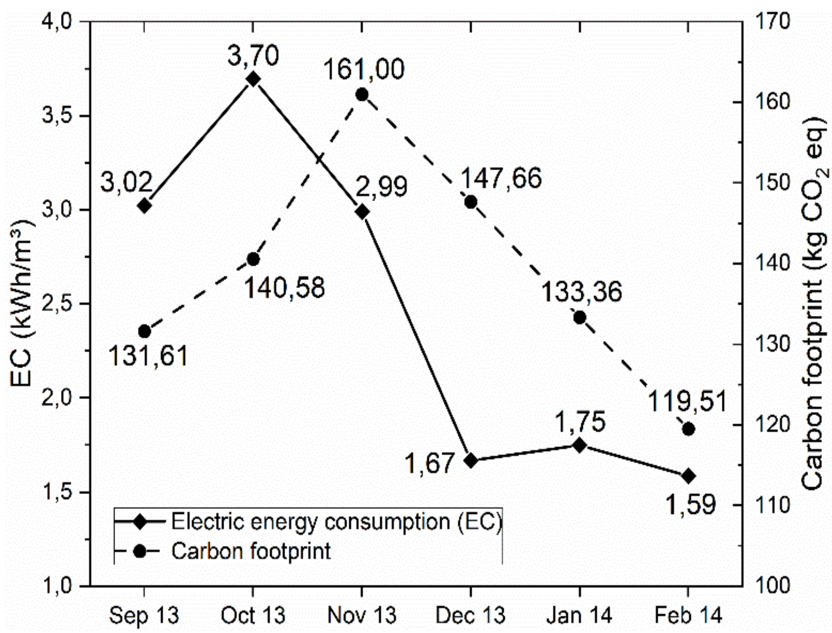

Figure 3: Electric energy consumption and Carbon footprint.

Figure 4 shows that the productivity index of labor is a decisive factor determining the total productivity index. During the diagnostic period from September to November, five workers only produced 3000 pallets per month due to the ineffectiveness of the machinery, the lack of training of the workers and the unsafe working conditions. The slight increase in productivity observed during the first three months might also be related to the Hawthorne Effect, meaning that the performance of the workers increased as their working habit was observed during the study.

With training, supervision and the other previously described measures, the same number of pallets were produced by only 3 workers in the last three months. This resulted in a drastic increase in the productivity index of labor by three times in the first month after implementation of the new measures. Later on, the productivity index of labor remained at 39 which means that by each dollar invested in labor the sawmill earns 39 dollars in sales.

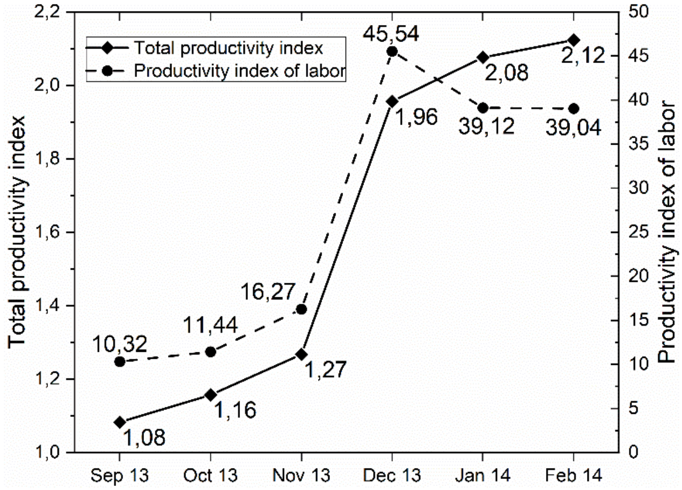

Figure 4: Total Productivity index and productivity index of labor.

The total productivity index changed from an average of 1,17 to around 2,05 after BMPs. In other words, without BMPs the sawmill only worked to cover the operative costs without a pronounced profit as the operative cost was 85% of the total sales. With the measures applied, the sawmill reduced its waste and increased its productivity. With approximately the same amount of resources it achieves 1,75 times more sales and the expenses now represent only 49% of the profit.

Chi-squared test result

After applying the BMPs procedures, the manager and workers again answered the surveys to obtain the information necessary to test our BMPs acceptance hypothesis. The responses were completely different from the first survey. Now, the manager was aware of the importance of buying good quality raw materials and that they should be ordered according to the demand. Moreover, he began to supervise work to ensure the efficient use of materials and quantify the amount of waste. He insists on not changing the old machines, but he has taken actions to provide maintenance to reduce waste and energy consumption, as well as supplying personal protection equipment to all workers of the sawmill. After verifying the effectiveness of BMPs in improving the productivity and profit, he expressed that he wanted to continue applying the actions taken.

After the training, the workers learned to check the logs before putting them into the machines to avoid damages to the machine, to shut down the machinery after finishing work to save energy, to clean their workplace and to wear personal protective equipment to avoid accidents. They also agreed that the BMPs improved the productivity and safety of the sawmills.

Table 5: Contingency table.

QUESTIONS	YES	NO	TOTAL
MANAGER: Should the sawmill invest in BMPs, which improves the manufacturing process, generates less environmental impact, provides safety for workers and increases profit?	1	0	1
WORKERS: Does the sawmill provide the necessary conditions to avoid occupational hazards during the production process?	23	2	25
TOTAL	24	2	26

Table 5 is the contingency table used to calculate the Chi-squared test. The first question was answered by the manager and the second one by the workers. The number of Yes or No answers were used to calculate the observed frequencies (*fo*) and the expected frequencies (*fe*) following the Equation 3. For example, the calculation of the first frequency is shown in the following Equation 5:

$$fe = \frac{(1)\,x\,(3)}{26} = 0{,}12 \quad (5)$$

Table 6 shows the Chi-squared test results for every option, calculated using Equation 4, resulting in a total, X_c^2 =7,64 which is greater than the theoretical value of 6,63. Consequently, the BPMs acceptance hypothesis can be accepted. Therefore, it can be said that BPMs are positively received by employees and improve working conditions.

Table 6: Chi-squared test.

ALTERNATIVES	fo	fe	X_c^2
Should the sawmill invest in BMPs, which improves the manufacturing process, generates less environmental impact, provides safety for workers and increases profit?			
YES	1	0,12	6,45
NO	0	0,88	0,88
Does the sawmill provide the necessary conditions to avoid occupational hazards during the production process?			
YES	23	2,88	0,27
NO	2	22,12	0,04
TOTAL X_c^2			**7,64**

CONCLUSIONS

In conclusion, a successful implementation of RECP in the sawmill of Puyo city depends on several factors. First, the measures should be adjusted to the actual production process, the economic investment should be low, and most important, the economic and environmental benefits must be tangible in the short term. Second, it is essential to raise awareness and encourage staff to participate actively in the BMPs implementation to generate changes in the behavior and to create a working culture which aims at minimizing waste.

The Best Management Practices in Maderol were simple measures that not only changed the production process, but also the functions, responsibilities, and mentality of the manager and employs. Furthermore, their productivity improved when they perceived that the manager was interested in their health and safety and collegiality and communication between all employees enhanced.

The main challenge that this study faced during its development was the little amount of information about BMPs in the SMEs and the lack of knowledge of the sawmill managers about the technical process. This made it challenging to detect technical problems and to elaborate appropriate RECP measures. However, simple measures were implemented, which not only changed the production process but also changed the functions and responsibilities of the employees. The effectiveness of the changes was obvious as the waste was reduced by 18%, and the Chi-squared test verified our hypothesis, that BPMs are positively received by employees and improve working conditions.

We recommend implementing the guide of Best Management Practices in other sawmills or SMEs in general. Additionally, to the economic and environmental benefits, the BMPs also generate a company culture where regulations and procedures that improve the organization of the SMEs are followed. Furthermore, we demonstrated that Maderol with the implementation of BMPs reduced its waste from 65% to 43%, increasing the profit by a factor of 1,75. The 6 primary industries analyzed could also experience a similar improvement because their main problem is the amount of the waste generated in the process.

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