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Energy-efficiency measures at the Mexican maquiladoras

Nora MUNGUIA, Luis VELAZQUEZ, Javier ESQUER, Sara OJEDA

University of Sonora, Hermosillo, Mexico

Michael ELLENBECKER

University of Massachusetts, Lowell, United States

Markus WILL, Bernd DELAKOWITZ

University of Applied Sciences Zittau/Görlitz, Germany[1]

Abstract: The energy consumption worldwide by the industrial sector is expected to keep increasing during the coming years; generating greenhouse gas (GHG) emissions as unwanted byproducts. For that reason, industrial facilities must take concrete initiatives in order to decouple their production growth from their CO2 emission generation in order to decrease their contributions to global warming. Concerned that this is a world-wide problem, Mexican maquiladoras have started several energy-efficiency initiatives. The aim of this article is to present significant results of a descriptive and analytical study that has been conducted into three maquiladoras located at northwestern Mexico of the first two stages of the Cleaner Production - Energy Efficiency program proposed by the United Nations Environment Programme. Findings reveal that, although electrical devices seem work efficiently, it is still possible to address energy waste. Additionally, attaching the energy-efficiency approach to the cleaner production framework was found a complicated task because, unlike emissions and toxic residues, energy inefficiencies are not easily visible, verifiable, or measurable.

Keywords: energy efficiency, energy audits, Mexico, maquiladoras, climate change
JEL: Q40, Q47, Q49

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Correspondence Address: Luis Velazquez, University of Sonora, Hermosillo, Mexico. E-mail: Luis_Velazquez@industrial.uson.mx.

1. Introduction

The actual economic growth of any single country has been accompanied with an accelerated energy consumption that has doubled worldwide in the past forty years (Kontorovich et al., 2014: 534-543). According to Matsuo et al. (2013: 79-91) the energy demand has been expanding rapidly from 5000 million tons of oil equivalent (Mtoe) in 1971 to 11,700 Mtoe in 2010.

The energy consumption worldwide by the industrial sector alone is expected to grow by an average of 1.4% per year from 2010 to 2040 (Bilgen 2014: 890-902). Given the fact that almost two thirds of the world's energy resources are used in production lines (Al-Shehri 2000: 719-726), energy efficiency has become a key element to maintaining industrial competitiveness (Apostolos et al., 2013: 628-633).

On the other hand, the production of this required energy has had a heavy dependence on fossil fuels which has generated greenhouse gas (GHG) emissions, primarily CO_2, as unwanted byproducts. Consequently, a worldwide concern has arisen about the contributions of carbon fuel emissions to global warming since CO_2 emissions are known as the biggest contributors to Climate Change (Morrison, Hatfield-Dodds 2011: 269-281). According to the Intergovernmental Panel on Climate Change (2014), energy-intensive activities are of the highest relevance for the CO_2 emissions trend because fossil-fuel combustion accounts for 90% of total CO_2 emissions, excluding deforestation and other land uses.

For that reason, the industrial sector must take concrete initiatives in order to decouple its production growth from its CO_2 generation on the presumption that it will decrease its contribution to global warming. Olanrewaju and Jimoh (2014) claim that increased energy efficiency is crucial for sustainable development. Aimed at this target, energy management practices in the United States of America (USA), as in many others countries, are one of the primary interventions of many voluntary government programs (Boyd, Curtis 2014: 463-479) which are strongly associated with higher productivity at the establishment level (Martin et al., 2013: 208-223). However, implementing these energy efficiency initiatives is not an easy task because supporters usually face several barriers such as internal economic and behavioral barriers (Brunke et al., 2014: 463-479) and high investment costs (Fleiter et al., 2012: 509-525). As a consequence, the implementation rate of the suggested energy efficiency improvement measures has been about 53% (Backlund, Thollander 2014: 54-60).

A core tool underpinning energy management practices is the energy audit; which contributes to the rational use of energy resources (Xuezhi, Ying 2011: 1893-1897). Audits have been found helpful in gathering useful information in order to increase energy efficiency not only in industry (Shen et al., 2012: 346-358) but also in the residential sector (Murphy 2014: 398-407) as well as in public buildings (Annunziata et al., 2014: 364-373), being another key economy sector for improving sustainability (Hedman et al., 2014: 408-418).

Energy audits are so promising that sometimes they lead to disappointment when energy bills do not decrease as much as it is expected (Shrivastaka et al., 2013: 291-294). Improving energy efficiency beyond “low-hanging-fruit”, i.e. no cost or low-cost measures, requires substantial investment in process technologies. As those private investments will not return in the short term, external incentives, such as subsidies, are needed. On a more general level, rebound-effects may occur, i.e., improved energy efficiency may lead to an increase in consumption due to psychological factors and decreased marginal cost (Sorrel 2007:19). Thus, it is important to keep in mind that audits are just a tool and are not the sustainability panacea for eliminating anthropogenic greenhouse gas emissions.

Consequently, Mexican maquiladoras, concerned with this worldwide problem, have started several energy-efficiency initiatives. The aim of this article is to present significant results of a study that has been conducted into three maquiladoras located at northwestern Mexico of the first two stages of the Cleaner Production - Energy Efficiency program proposed by the United Nations Environment Programme.

2. Methodology

This is descriptive and analytical study based on the framework on a Cleaner Production Program focused on Energy Efficiency by the United Nations Environment Programme (2004). The framework consists of five stages: planning and organization; pre-assessment; evaluation; feasibility analysis; and implementation and continuity. However, for the purpose of this article, only data from the two first stages are presented.

The energy audits for the pre-assessment stage were carried out in three maquiladoras located in northwestern Mexico that produce electronic components, two located in Hermosillo, the capital city of the state of Sonora, and the other located in Mexicali, the capital city of the state of Baja California, both states are along the border with the USA. The period of the study was from October 2014 to May 2015.

Maquiladoras were chosen under a non-random purposive sampling method taking into account their interest to participate in the study. The small sample size and its non-random nature are limitations of this study, as obviously no representative and generalizable results can be obtained. However, this study stills allows gaining insight into energy efficiency improvement potentials in the maquiladoras.

Energy audits for pre-assessment in terms of the methodological approach are similar to Type 1 Energy Audits according to ISO 50001. They should be considered as a simplified and screening approach and not as a comprehensive and full audit. Those audits mainly rely on abbreviated walkthrough inspections, brief interviews with operating staff, and analysis of facilities energy/utility bills and additional data from equipment lists. The pre-assessments audits have the intention of roughly estimating the actual electricity consumption and identifying major consumers as well as low-cost and easy-to-implement energy performance measures.

The data were obtained from electricity bills and through direct observation. Finally, a thermographic camera FLIR model E5 was used to visualize potential energy losses through heat transfer.

3. Results

3.1 Maquiladora profiles

The first maquiladora is located in Mexicali; it produces power capacitors that are distributed worldwide. The company achieves yearly sales of around $ 120 million annually. Its building has a net floor area of 11 000 m^2 and it has 436 employees; 342 in production and 94 in indirect administration or staff services.

The second facility is located in Hermosillo, it has produced, since the latter half of the 1980s, wires, connectors, and radio-frequency equipment. Its building has a net floor area of 9

935.5 m^2 and it has 520 employees, 309 are in the production area and 211 in indirect administration or staff services.

The third company is also located in Hermosillo; it produces electrical harnesses, automotive components, and wires for transnational automotive companies. Its building has a net floor area of 25 000 $m^2$and its labor force is comprised by 3 000 employees.

3.2 Management support

Although, supervisors did not know the framework of the Cleaner Production - Energy Efficiency Program, gaining management support from all three maquiladoras was not difficult since them were indeed aware of the need to reduce CO_2 emissions. Hence, once supervisors understood the potential benefits of this framework, they were very willing to conduct energy-efficiency audits as the first step to promote energy sustainability.

The energy sustainability commitment of the maquiladoras is written in their mission statements, which tell groups of interest the inspiration and motivation of maquiladoras for sustainability. Equally worthy of mentioning are their environmental policies that lead toward the purpose of reducing the generation of CO_2 emissions in their facilities by energy efficiency practices.

At each facility, the energy efficiency team consisted of a manager such as an operations manager, a quality manager or an environmental, health and safety manager, technicians, and three graduate students of the Masters in Sustainability degree of the University of Sonora who played the role of external consultants. It is a small team whose purpose was to conduct an energy efficiency audit as a diagnosis.

3.3 Pre-assessment

The purpose of this phase of the program is identifying all energy-related data that could be helpful in revealing energy inefficiencies as a foundation to set goals. However, finding opportunities to improve energy use is difficult because energy inefficiencies are not as visible as material waste.

The first step was to compile energy consumption records from energy bills. Table 1 shows the yearly energy records from 2012-2014 in all maquiladoras. At glance, maquiladora 3 is obviously the largest consumer of energy, approximately three times that the other two. In total, the energy consumption was more than 39 000 000 kilowatt hours over the three years.

Table 1. Yearly Electricity Consumption

Organization	Kilowatt hours per year			SUM
	2012	2013	2014	
Maquiladora 1	1 736 527	1 832 032	2 557 316	6 125 875
Maquiladora 2	3 292 328	2 730 000	3 125 013	9 147 341
Maquiladora 3	7 413 118	7 609 350	8 738 034	15 273 216
SUM	12 443 985	12 173 395	14 422 377	39 039 757

The next step was to convert those kilowatt hours (kWh) into environmental indicators, specifically in terms of tons of carbon dioxide (CO_2) equivalents, by using an emission factor, CF in Table 2, associated with the net electricity generated in the country by the Mexico GHG Program (SEMARNAT 2013). As shown in Table 2, the three maquiladoras experienced a growth in their tons of CO_2 equivalent (tCO_2-eq) emissions, during the period between 2012 and 2014, with a total of 19.7 million of tCO_2-eq. By placing this in perspective, one ton of CO_2 is emitted when burning 319 L of diesel or when traveling 25 000 km by train or when using 300 kg of standard office paper (Climate Neutral Group 2015).

Table 2. Yearly tCO_2-eq

Organization	Years									SUM tCO2-eq
	2012			2013			2014			
	Kwh	CF	tCO2-eq	Kwh	CF	tCO2-eq	Kwh	CF 2013	tCO2-eq	
Maquiladora 1	1 736 527	0.517	896 916	1 832 032	0.499	915 833	2 557 316	0.499	1 278 402	3 091 151
Maquiladora 2	3 292 328	0.517	1 700 487	2 730 000	0.499	1 364 727	3 125 013	0.499	1 562 194	4 627 408
Maquiladora 3	7 413 118	0.517	3 828 875	7 609 350	0.499	3 803 914	8 738 034	0.499	4 368 143	12 000 933
SUM	12 443 985	0.517	6 427 318	12 173 395	0.499	6 085 480	14 422 377	0.499	7 209 746	19 722 545

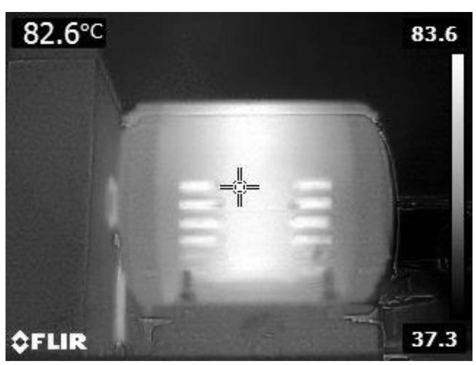
Aggregated data provided a general idea regarding energy consumption and tCO_2-eq emissions in the three maquiladoras. This was, however, obviously not enough to identify specific energy efficiency opportunities; to achieve this, a structured walkthrough of the entire facilities was necessary; nevertheless particular emphasis was placed on production workstations.

Based on the facility walkthrough, characterization of the use of electricity in each maquiladora was possible: electricity is mainly used to power motors, ovens, air compressors, lighting, and air conditioners. In order to estimate the consumption of energy per equipment, technical information was taken from the data plates on the devices. Finally, the physical condition of those devices was also observed.

The task of inventorying all energy-consuming devices is just the first step in identifying energy losses because they are usually not perceived directly; therefore, losses can be anywhere depending on many factors.

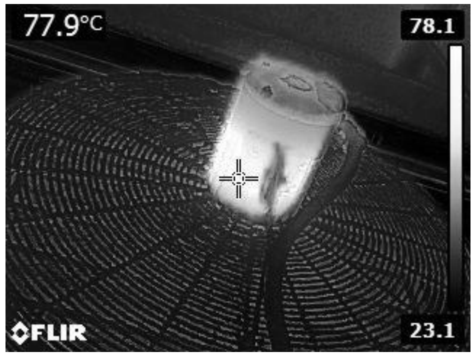
Additionally, with the knowledge that heat loss is one of the factors that lower devices efficiency, thermographic photographs were taken to visualize potential energy losses. In general, air conditioning systems seemed to be affected by the generation of heat from other devices such as motors and ovens. Electrical motors generate a very large amount of heat; in some cases, it is possible to exceed 80 °C, as shown in Figure 1. The use of fans for ventilation was found also is a problem because they were old appliances. At this regards, Figure 2 displays a fan that can work with temperatures reaching 78 C°. Furthermore, ovens in maquiladoras often are not insulated, as a result, conditioning systems work in unfavorable conditions consuming more energy than usual. Figure 3 and Figure 4 illustrate this situation. Finally, during walkthrough, several heat leaks were found in the piping systems. This contributes in the growth of the indoor temperature in the maquiladora facilities. See Figure 5.

Figure 1. Thermographic picture of a motor reaching 82.6 C°.



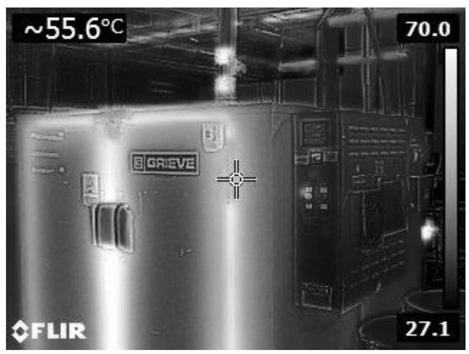
Source: Authors.

Figure 2. Thermographic picture of a fan reaching 77.9 C°.



Source: Authors.

Figure 3. Thermographic picture of an oven reaching 55.6 C°.

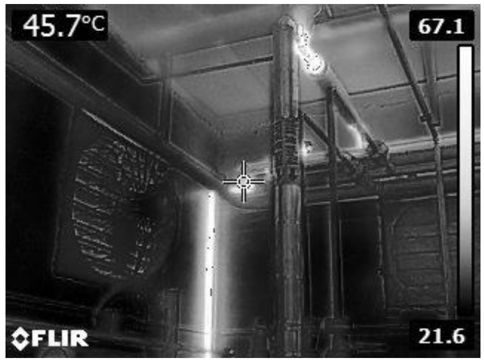


Source: Authors.

Figure 4. Thermographic picture of an oven reaching 98.7 C°.

Source: Authors.

Figure 5. Thermographic picture of heat leaks in piping systems reaching 45.7 C°.



Source: Authors.

4. Conclusions

Evidence of the contribution of the energy sector to climate change is unequivocal; thus, during the last decade Mexican maquiladoras, concerned with this world-wide problem, have started several energy-efficiency initiatives.

At first glance, electrical devices seem to work efficiently; however, energy waste is still possible. For this reason, integration of Cleaner Production and Energy Efficiency measures under a single framework might be convenient. This is tempting; however, this article has shown that attaching the energy-efficiency approach to the cleaner production framework has proven to be a complicated task because, unlike emissions and toxic residues, energy inefficiencies are not easily visible, verifiable, or measurable.

Conducting energy audits helped to reveal those energy inefficiencies that were missed for a long time in the three maquiladoras. For this, the audit committee played a key role in the quality assurance of data reporting.

Key indicators, as shown in Table 3, reveal that the relationship between consumption (kWh) and floor space (m^2) is almost equivalent among the three companies. This is not the same with the relationship between consumption (kWh) and number of employees (emp) where maquiladora 3 resulted in a lower level.

Energy balances were very difficult to produce; although inputs were easy to identify on a site-level, sub-meter data are missing, which are necessary to monitor energy usage of single processes or equipment. It is however still difficult to quantify waste heat and other energy losses.

Table 3. Key energy indicators

	kWh/m^2	kWh/emp
Maquiladora 1	232.48	5 865.40
Maquiladora 2	314.53	6 009.64
Maquiladora 3	349.52	2 912.67

In this study, heat was considered an important parameter to identify energy losses and specialized equipment was required to do so; thus, a thermographic camera was used. Findings from this tool reveal that some heat losses surpassed 70 C° reaching almost 100 C°, being the most contributors an oven and a motor.

The scope of this study encompassed the two first stages of the framework of the Cleaner Production Program focused on Energy Efficiency by the United Nations Environment Programme which are the foundation. As a final point, it is highly expected that the baseline developed from gathered data will be used for developing further stages of the framework, and eventually, create design tailored measures that allow the participant maquiladoras a better energy efficiency in their operations. There is still much to be done to ensure an efficient use of energy within the participant maquiladoras, but the main steps have been taken to integrate Cleaner Production and Energy Efficiency approaches in order to get effective environmental and economic results.

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Narzędzia na rzecz poprawy efektywności energetycznej w meksykańskich maquiladoras

Streszczenie:

Oczekuje się, że w ciągu najbliższych lat w sektorze przemysłowym na całym świecie będzie wzrastać konsumpcja energii, prowadząc do zwiększenia emisji gazów cieplarnianych (ang.: greenhouse gases (GHG)) jako niechcianego produktu ubocznego. Z tego względu przedsiębiorstwa przemysłowe muszą podjąć konkretne inicjatywy, aby oddzielić wzrost produkcji od wzrostu emisji GHG i tym samym zmniejszyć swój wkład w globalne ocieplenie. Uznając światową skalę tego problemu, meksykańskie maquiladoras (przedsiębiorstwa produkcyjne) podjęły kilka działań mających na celu podniesienie efektywności energetycznej. Celem artykułu jest przedstawienie istotnych wyników badań opisowych i analitycznych, przeprowadzonych w trzech maquiladoras zlokalizowanych w północno-zachodnim Meksyku uczestniczących w dwóch pierwszych z trzech etapów programu Czystsza Produkcja – Wydajność Energetyczna (ang.: Cleaner Production – Energy Efficiency Program) uruchomionego w ramach Programu Środowiskowego Organizacji Narodów Zjednoczonych (ang.: United Nations Environment Programme). Wyniki badań ukazały, że choć urządzenia elektryczne zdają się pracować w sposób wydajny, nadal możliwe są straty energii. Co więcej, zastosowanie podejścia opartego na efektywności energetycznej w ramach czystszej produkcji okazało się skomplikowanym zadaniem, ponieważ – w przeciwieństwie do emisji zanieczyszczeń, gazów cieplarnianych oraz toksycznych odpadów – nieefektywność energetyczna nie jest łatwo dostrzegalna, weryfikowalna czy mierzalna.

Słowa kluczowe: efektywność energetyczna, audyty energetyczne, Meksyk, maquiladoras, zmiany klimatyczne

JEL: Q40, Q47, Q49