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ANALYSIS OF ENERGY EFFICIENCY IN PRODUCTION LINES THROUGH THE IMPLEMENTATION OF INDUSTRY 4.0 TECHNOLOGIES

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ABSTRACT

Objective: This article aimed to verify the impact of new technologies and concepts of Industry 4.0 on the energy efficiency of the production processes of a company in the automotive sector, an assembly plant.

Theoretical Framework: It addresses theoretical contributions on technological innovations in industry, concepts and technologies embedded in Industry 4.0, and technological innovations as a means of improving energy efficiency in production processes.

Method: Through the energy consumption generated in the company's production areas and in its lighting system, an analysis of the improvement in energy efficiency was carried out using technologies and concepts prior to Industry 4.0 technologies and an analysis of the energy efficiency of the same environments when possible already using the new Industry 4.0 technologies. With the two surveys obtained, an analysis and comparison of the results achieved was carried out.

Results and Discussion: The results demonstrated that there were energy savings and improvements in the energy efficiency of the environments using both technologies, but with Industry 4.0 technologies it became clearer the possibility of maintaining the efficiency achieved and analyzing the data generated.

Research Implications: It is crucial to intensify technical updates, improve internet infrastructure and develop public policies that encourage digital innovations. University extension projects focused on technological innovations and artificial intelligence are relevant.

Originality/Value: The research provides real data on energy consumption in production areas of an assembly company, highlighting the actions to reduce and improve efficiency in its production processes over time and the technologies used for this action, comparing the technologies used before the advent of Industry 4.0 and after with the use of new Industry 4.0 technologies and their results.

Keywords: Energy Efficiency, Industry 4.0, Automotive Industry, Efficiency Indicators.

ANÁLISE DA EFICIÊNCIA ENERGÉTICA EM LINHAS DE PRODUÇÃO ATRAVÉS DA IMPLANTAÇÃO DE TECNOLOGIAS DA INDÚSTRIA 4.0.

RESUMO

Objetivo: Este artigo teve como objetivo verificar o impacto das novas tecnologias e conceitos da Indústria 4.0, na eficiência energética dos processos de produção de uma empresa do ramo automobilístico, uma montadora.

Referencial Teórico: Aborda as contribuições teóricas sobre inovações tecnológicas na indústria, conceitos e tecnologias embutidas na Indústria 4.0, e as inovações tecnológicas como meio de melhorar a eficiência energética em processos de produção.

Método: Através do consumo energético gerado nas áreas produtivas da empresa e em seu sistema de iluminação, foi realizada uma análise da melhora da eficiência energética utilizando tecnologias e conceitos anteriores as

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tecnologias da indústria 4.0 e uma análise da eficiência energética dos mesmos ambientes quando possível já utilizando as novas tecnologias da Indústria 4.0. Com os dois levantamentos obtidos, foi realizado uma análise e comparação dos resultados alcançados.

Resultados e Discussão: Os resultados demonstraram que houve economia de energia e melhora da eficiência energética dos ambientes utilizando as duas tecnologias, porém com as tecnologias da Indústria 4.0 ficou mais claro a possibilidade de manutenção da eficiência alcançada e da análise dos dados gerado.

Implicações da Pesquisa: É crucial intensificar a atualização técnica, melhorar a infraestrutura de *internet* e desenvolver políticas públicas que incentivem inovações digitais. Projetos de extensão universitários direcionados as inovações tecnológicas e inteligência artificial são pertinentes.

Originalidade/Valor: A pesquisa fornece dados reais sobre o consumo energético em áreas produtivas de uma empresa montadora, destacando as ações de redução e melhora da eficiência em seus processos de produção durante o tempo e as tecnologias utilizadas para esta ação, comparando as tecnologias utilizadas antes do advento da Indústria 4.0 e após com o uso das novas tecnologias da Indústria 4.0 e seus resultados.

Palavras-chave: Eficiência Energética, Indústria 4.0, Indústria Automotiva, Indicadores de Eficiência.

ANÁLISIS DE LA EFICIENCIA ENERGÉTICA EN LÍNEAS DE PRODUCCIÓN MEDIANTE LA IMPLEMENTACIÓN DE TECNOLOGÍAS DE LA INDUSTRIA 4.0.

RESUMEN

Objetivo: Este artículo tuvo como objetivo verificar el impacto de las nuevas tecnologías y conceptos de la Industria 4.0 en la eficiencia energética de los procesos productivos de una empresa del sector automotriz, una planta de ensamblaje.

Marco Teórico: Aborda las aportaciones teóricas sobre las innovaciones tecnológicas en la industria, los conceptos y tecnologías insertos en la Industria 4.0, y las innovaciones tecnológicas como medio para mejorar la eficiencia energética en los procesos productivos.

Método: A través del consumo energético generado en las áreas de producción de la empresa y en su sistema de iluminación, se realizó un análisis de la mejora en la eficiencia energética utilizando tecnologías y conceptos previos a las tecnologías de la Industria 4.0 y un análisis de la eficiencia energética de los mismos entornos cuando es posible ya utilizando las nuevas tecnologías de la Industria 4.0. Con las dos encuestas obtenidas se realizó un análisis y comparación de los resultados alcanzados.

Resultados y Discusión: Los resultados demostraron que hubo ahorros energéticos y mejoras en la eficiencia energética de los entornos utilizando ambas tecnologías, pero con las tecnologías de la Industria 4.0 se hizo más clara la posibilidad de mantener la eficiencia alcanzada y analizar los datos generados.

Implicaciones de la investigación: Es crucial intensificar las actualizaciones técnicas, mejorar la infraestructura de Internet y desarrollar políticas públicas que incentiven las innovaciones digitales. Son relevantes los proyectos de extensión universitaria orientados a las innovaciones tecnológicas y a la inteligencia artificial.

Originalidad/Valor: La investigación proporciona datos reales sobre el consumo energético en las áreas de producción de una empresa de montaje, destacando las acciones para reducir y mejorar la eficiencia en sus procesos productivos a lo largo del tiempo y las tecnologías utilizadas para esta acción, comparando las tecnologías utilizadas antes de la llegada de la Industria 4.0 y después con el uso de las nuevas tecnologías de la Industria 4.0 y sus resultados.

Palabras clave: Eficiencia Energética, Industria 4.0, Industria Automotriz, Indicadores de Eficiencia.

1 INTRODUCTION

The industrial sector has always been crucial to the economic development of countries. Since the end of the 18th century, the industry has undergone transformations that have revolutionized the way products are manufactured and brought several benefits, especially in terms of increased productivity.

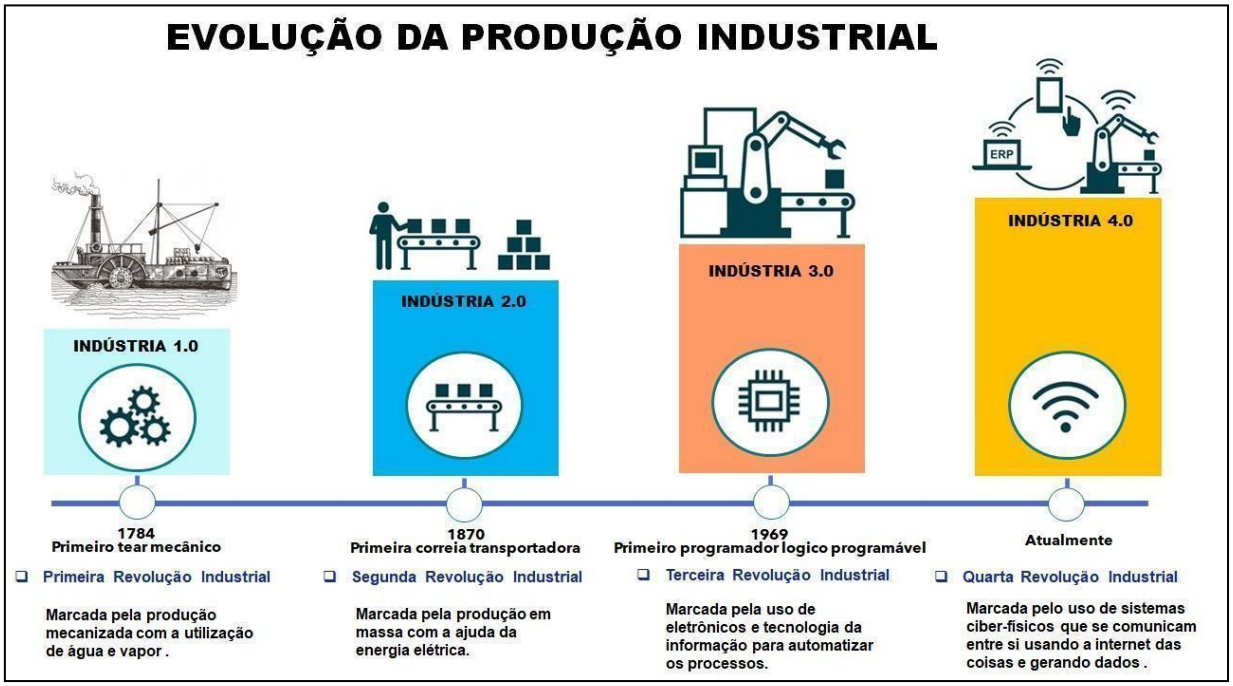
The first Industrial Revolution was marked by the transition from manual labor to steam-powered machines. At the beginning of the 20th century, with the introduction of electricity into production systems, the second Industrial Revolution began, characterized by mass production and division of labor. The third Industrial Revolution, which lasted from the 1970s to the present day, is characterized by the use of electronics and information technology (IT) to improve automation in production (BITKOM et al., 2016).

The combination of advanced technologies and the internet is once again transforming the industrial landscape, and is being called the 4th Industrial Revolution or Industry 4.0 (LASI et al., 2014).

Figure 1 presents a summary of the four Industrial Revolutions.

Figure 1

Industrial Revolutions



Source: (Adapted from BERGER,2016).

The object of study of this work is the impact of new technologies and concepts of Industry 4.0, visualizing their action on the energy efficiency of the production processes of a company in the automotive sector, an assembly plant.

The concept of process according to SORTINO (2017) is a continuous operation, with a beginning, middle and end, which serves to compose an activity with the objective of achieving expected results within control parameters. In this sense, industrial processes are continuous activities that can be very varied, covering procedures in mechanical industries, and which can also include stages of physical, electrical and chemical transformations in specific steps with the objective of producing a part or parts, which can be in low quantities and even in high volumes.

According to SORTINO (2017), a second important concept also linked to the process is that of energy efficiency, which "consists of obtaining the best performance in the production of a service with the lowest energy expenditure", often requiring the "modernization of equipment and processes in order to reduce their consumption".

The work aims to explore the actions taken by the company to improve its energy efficiency before the introduction of Industry 4.0 concepts and technologies, and the actions taken using these new technologies.

One of the indicators most used in comparing results is the indicator resulting from the energy consumption used in the year by the company, divided by the number of vehicles produced. Thus, the indicator used in all comparisons is the annual energy expenditure per vehicle produced.

The use of indicators aimed at assessing the energy efficiency of industrial processes has been growing in importance worldwide and in Brazil. The results of an analysis of energy efficiency indicators may be linked to strategic planning, environmental management and technology, and energy conservation actions. In practice, it is worth highlighting that the application of the analysis of these indicators and their relevance in describing the interrelationship between energy efficiency and the resources consumed are mainly associated with economic and political-environmental factors within the industry (MONTEIRO, 2013).

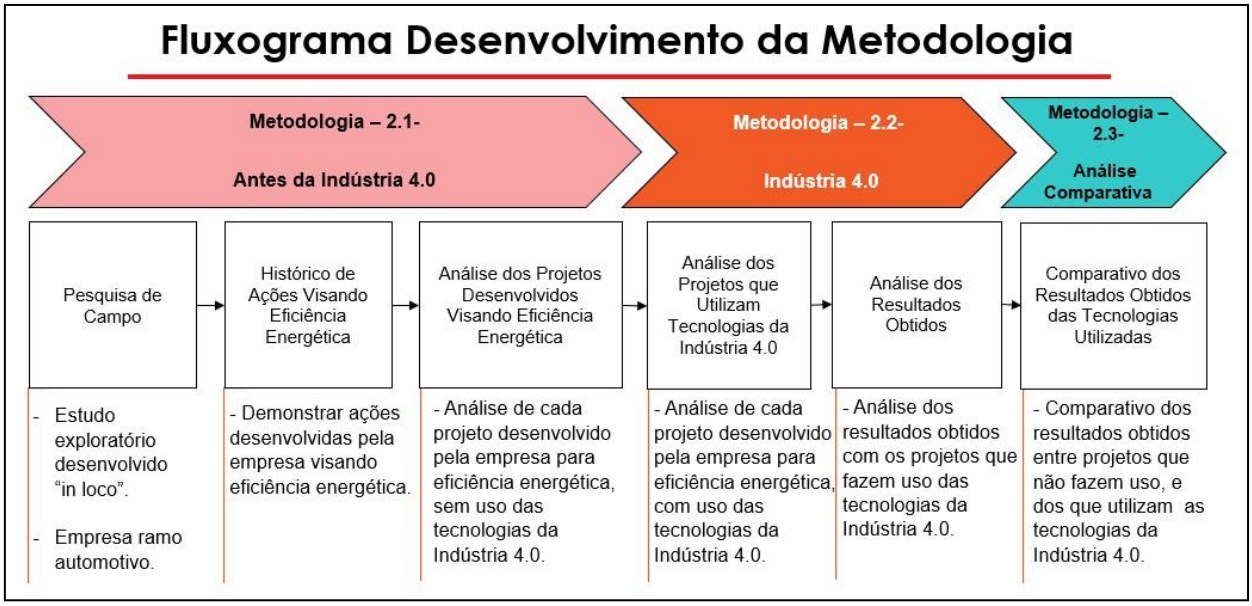
In general, the main objective of this work is to analyze the improvement in energy efficiency obtained in industrial processes, which are part of processes controlled and monitored by technologies and concepts originating from Industry 4.0.

2 METHODOLOGY

The topics covered in this research are multidisciplinary and transversal in nature, permeating different areas such as engineering, physics, chemistry, environment, economics and management. Thus, the guideline chosen for the preparation of the study is guided by the traditional Explanatory Research Methodology, structured on bibliographical research, comparison of collected data and use of deductive logic. The research consists of guiding points, analyzed and consulted according to the intentions mentioned below, and demonstrated in the flowchart in figure 2:

Figure 2

Methodology Flowchart



Source: (Author's own).

2.1 WHAT WAS DONE BEFORE INDUSTRY 4.0 TECHNOLOGY TO IMPROVE ENERGY EFFICIENCY

In this initial phase of the research, we sought to understand all the actions that were carried out in the company with the aim of improving its energy efficiency, and the results obtained with the technologies existing at the time of the action.

Through an exploratory study that was developed on site, that is, based on a case study in an automotive company, in which data from controls carried out on the consumption and

expenditure of electrical energy supplied for the operation of the company's production areas were investigated.

The study considered the history of actions developed by the company, using the year 2008 as the initial date, focusing on energy efficiency mainly in power supply substations. The aim was to see how much each action developed using technologies prior to Industry 4.0, provided an improvement in the energy efficiency of the electricity supply process.

Each project presented as a means of improving energy efficiency since 2008 completed in the company was analyzed and used in the comparison of projects that have already begun to be carried out using technologies and concepts from Industry 4.0.

The following were taken into account in the analysis of each project developed: Project implementation time, project cost, ease of use of technology, security and reliability of data obtained in the project, and ease of obtaining and monitoring project data.

2.2 WHAT IS BEING DONE USING INDUSTRY 4.0 CONCEPTS AND TECHNOLOGIES, IN RELATION TO IMPROVING ENERGY EFFICIENCY

In this secondary phase of the research, we sought to understand all the actions that were carried out in the company with the aim of improving its energy efficiency, and the results obtained with the concepts and technologies from Industry 4.0 used in the action.

Since 2016, the company has been seeking to adapt its processes to technologies and concepts from Industry 4.0. Projects were initiated to adapt controls that were already used in the company to monitor energy efficiency, but now with an Industry 4.0 vision and with the prediction of new means of control through current technologies.

All projects implemented in the factory using Industry 4.0 concepts and technologies were verified, and are used to monitor and improve the factory's energy efficiency in its processes, together with the results provided by these projects since their application.

2.3 ANALYSIS AND COMPARISON OF THE USE OF THE TWO TECHNOLOGIES TO IMPROVE ENERGY EFFICIENCY

In this final phase of the research, we sought to understand all the actions that were carried out in the company with the aim of improving its energy efficiency, through the analysis of the results obtained from the technologies existing at the time of the action.

A comparison of the results obtained in improving energy efficiency was prepared, in which actions that use technologies and equipment prior to the implementation of Industry 4.0 technologies were analyzed, and actions that are already carried out within the concepts of Industry 4.0.

The following were taken into account in this comparison: Project implementation time, project cost, ease of use of technology, security and reliability of data obtained in the project, and ease of obtaining and monitoring project data.

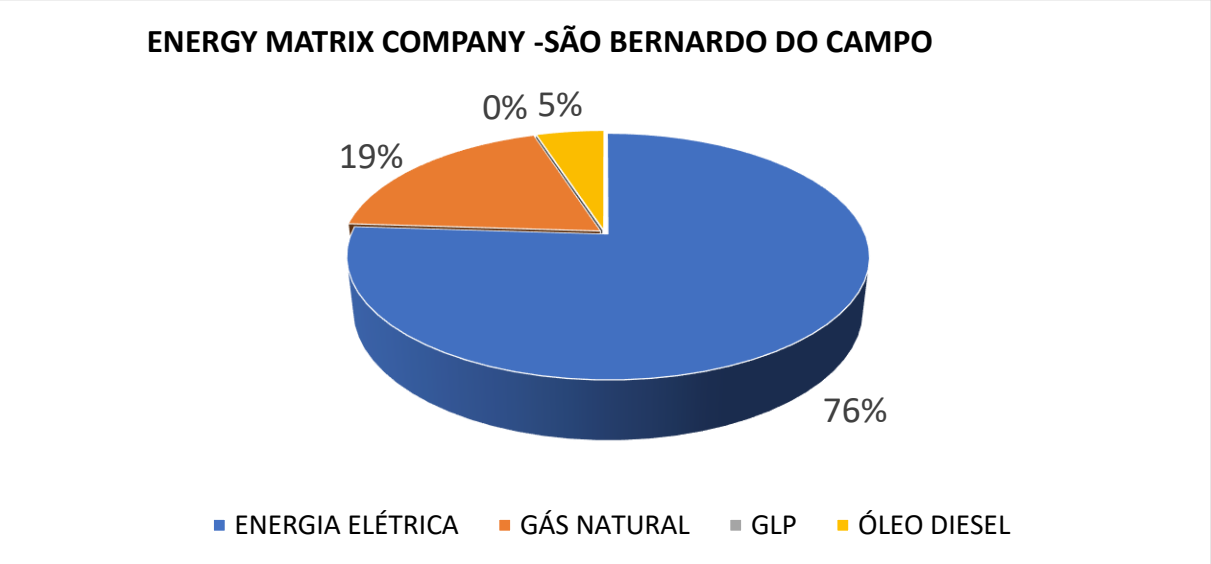
3 RESULTS

There is an area in the company responsible for receiving, controlling and supplying electrical energy for the company's industrial processes. This area is called the Maintenance Strategy and Electrical Supply System – OPF -. In this work, only the acronym OPF will be used when discussing the supply area.

Electricity is the main input used by the company to generate work, as shown in figure 3, which represents the Energy Matrix of the São Bernardo do Campo unit.

Figure 3

Energy Matrix Chart



Source: (VICENTE,2024)

The OPF receives electrical energy from its contractual supplier, controls and distributes this energy to the company's production areas, and discloses data on the expenditure of this energy to the responsible areas of the factory, as shown in table 1.

Table 1

Annual control of electrical energy consumption per vehicle produced

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Specific Consumption (MWh/Veic)	2.79	2.97	2.59	2.50	3.26	2.59	2.99	3.47	4.34	3.29	3.09	2.66	3.28	2.28	2.22

Before Industry 4.0 After Industry 4.0

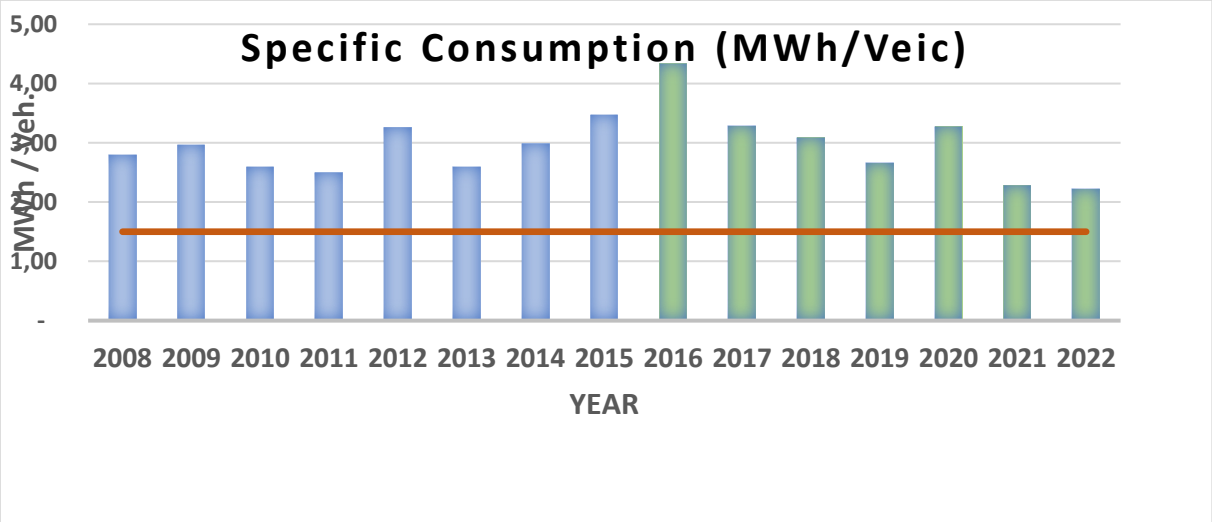
Source: (VICENTE,2024)

Table 1 presents data that configure the annual consumption of electrical energy carried out by the company in total, the electrical energy consumption uses the unit MWh, divided by the quantity of vehicles that were produced by the factory in this same period, which is represented by the unit Veic, therefore, the values presented in this table are data that generate an indicator of energy consumed in the year per vehicle produced, whose unit will be MWh/Veic.

Transforming table 1 into a graph, we have the following situation presented in figure 4:

Figure 4

Graph of annual control of electrical energy consumption per vehicle produced.



Source: (VICENTE,2024).

It can be seen that the years analyzed before Industry 4.0 technologies, from 2008 to 2015, are periods in which electricity consumption varied from 2.79 MWh/Vehicle to 3.47 MWh/Vehicle. In the years in which a process of using technologies inherent to Industry 4.0

began, from 2016 to 2022, electricity consumption varied from 4.34 MWh/Vehicle to 2.22 MWh/Vehicle.

A variation is presented demonstrating an increase in electricity consumption per vehicle produced in the years 2009, 2012, 2014, 2015, 2016 and 2020, due to low vehicle sales. The lower the vehicle production volume, the lower the energy efficiency of the factory's production in its industrial processes, since the energy required to keep its processes running remains the same, an average of 1.5 MWh/Vehicle per month.

For a better understanding of the actions to improve energy efficiency of the data shown in table 1 and the graph in figure 4, we will analyze them through the periods and projects developed in these respective years of control of electricity consumption per vehicle produced, periods and results obtained before the use of industry 4.0 concepts, and periods and results obtained after the use of industry 4.0 concepts.

3.1 RESULTS OBTAINED FROM ENERGY EFFICIENCY PROJECTS WITHOUT USING INDUSTRY 4.0 CONCEPTS

From 2008 to 2015, the company carried out projects aimed at improving its energy efficiency in industrial processes, as well as projects focused on reducing waste in processes that involved only human action.

3.1.1 Energy efficiency projects carried out in 2015

In 2015, there was an action coordinated by the OPF, together with several sectors of the company, aiming at saving, improving processes and combating the waste of electrical energy. Among the actions carried out, we can highlight those that had the greatest effect on energy savings:

- **Compressed air loss control project.**

At the company's Utilities Center, where compressed air is produced and distributed to all sectors, the following actions were taken:

1. Closing of compressed air supply valves during non-productive hours and weekends;
2. Installation of flow meters in the buildings' power supply;

The result obtained by this action in 2015 was energy savings of 1000MWh (VICENTE, 2024).

Energy value per MWh = R$61.07 + R$62.46 = R$123.53 per MWh, value that will be used in all calculations (VICENTE, 2024). Which generated a monetary saving of R$123.53 X 1000MWh = R$123,530.00 or US$24,706.00 (VICENTE, 2024).

- **Control project in the supply of other utilities.**

At the company's Utilities Center, where cold and cooling water are also supplied, and steam and thermal oil are supplied to the factory, the following actions were taken:

1. Mapping of infrastructure supply systems;
2. Analysis of changes in the functioning of systems.

The result obtained by this action in 2015 was energy savings of 1000MWh (VICENTE, 2024). This generated monetary savings of R$123.53 X 1000MWh = R$123,530.00 or US$24,706.00 (VICENTE, 2024).

- **Production shutdown project (Machinery and Equipment).**

In the production areas, care was taken to raise awareness among machine operators and production supervisors so that during idle production periods, equipment that was not in use and where possible, should be turned off. This was the main action, along with others that were:

1. Study of machines and peripherals;
2. Dissemination of knowledge for shutting down machines and equipment;
3. Monitoring energy consumption during non-productive hours (machines on stand-by).

The result obtained by this action in 2015 was a saving of 6000MWh (VICENTE, 2024).

Which generated a monetary saving of R$123.53 X 6000MWh = R$741,180.00 or US$148,236.00 (VICENTE, 2024).

- **Lighting systems control project.**

To reduce electricity consumption, a general awareness campaign was carried out at the company with employees, focusing on the correct use of spaces and turning off the lighting system when the space was no longer being used. The following actions were also carried out:

1. Survey of lighting loads (external, internal and offices);
2. Elimination of excess lighting (above the value defined by standard);
3. Analysis of external proposals (new technologies);

The result obtained by this action in 2015 was a saving of 650MWh (VICENTE, 2024).

Which generated a monetary saving of R$123.53 X 650MWh = R$80,294.50 or US$16,058.9 (VICENTE, 2024).

In 2015, the company had predicted a consumption of 144,650 MWh per year for its operation, without considering any reduction action (VICENTE, 2024).

The total sum of the values obtained in energy reduction expressed in MWh were: 1,000MWh +1,000 MWh +6,000MWh +650MWh = 8,650 MWh of total savings.

The value of 8,650 MWh represents an approximate saving of 6% in the total energy needed for the company to operate this year (VICENTE, 2024). Which represents a saving in reais of R$ 123.53 x 8,650 MWh = R$ 1,068,534.50 or US$ 213,706.9 (VICENTE, 2024).

In table 2 shown below, we can see the values that were achieved with each project carried out in 2015:

Table 2

Results obtained with Energy Efficiency Projects carried out in 2015.

Savings in Electricity Consumption	MWh	R$ thousand US$
Compressed air losses ↰ *Reducing air leaks* ↰ *Blockage of supply pipelines during non-productive time*	1,000	R$ 123,530.00 US$ 24,706.00
Provision of other utilities ↰ *Cold and cooling water supply (pumps and equipment)* ↰ *Steam and thermal oil supply*	1,000	R$ 123,530.00 US$ 24,706.00
Production (Machinery and Equipment) ↰ *Shutdown of machines and equipment during non-productive time*	6,000	R$ 741,180.00 US$148,236.00
Lighting Systems ↰ *Reducing "lighting systems" to the minimum permitted levels*	650	R$ 80,294.50 US$ 16,058.9
TOTAL	**8,650**	**R$1,068,534.50 US$ 213,706.9**
% Reduction considering 144,650 MWh	**6.0%**	

Source: (VICENTE, 2024).

Therefore, in 2015, the company achieved savings in its energy efficiency projects of approximately 8,650 MWh per year, which represents savings of R$1,068,534.50 or US$213,706.90 (VICENTE, 2024).

3.2 RESULTS OBTAINED FROM ENERGY EFFICIENCY PROJECTS USING INDUSTRY 4.0 CONCEPTS

In 2017, the factory adopted a new LED Lighting System, already using IoT, Big Data and Machine Learning technologies. In 2018, the truck production factory was remodeled, using all the concepts of Industry 4.0, and in 2019, the bus chassis production factory also had all its production processes remodeled and adapted to Industry 4.0 technologies.

3.2.1 LED lighting project completed in 2017

In 2017, the company's plant underwent a major transformation in its lighting system. A lighting design and planning was carried out for the factory's 1 million square meter space. An intelligent lighting system was used using IoT, Big Data and Machine Learning resources. The system provides automated lighting operation, generating energy savings. The controls detect the amount of natural light in the location, ensuring that artificial light is used only when necessary; they check for movement to determine the lighting intensity; and check whether the light points can be turned off (VOLTIMUM, 2020).

It was found that after the implementation of the Lighting Project, it was possible to reduce the factory's energy demand contract with the generating company by 1 MW on average, which, when converted into monthly measurements, would be a consumption of 720 MWh/month (1 MW * 24 hours * 30 days = 720 MWh/month). The result achieved in one year of energy savings in this action was 720 MWh/month x 12 months = 8,640 MWh/year.

With the monthly savings of 720MWh/month, it was also possible to reduce the amounts spent on the annual energy bill, calculated as follows: Monetary savings in reais = R$123.53 X 8,640MWh = R$1,067,299.20 or US$213,459.84 (VICENTE, 2024).

Therefore, in 2017, the company achieved savings in its LED Lighting Project of approximately 8,640 MWh per year, which represents savings of R$1,067,299.20 or US$213,459.84 (VICENTE, 2024).

3.2.2 Truck Factory Project 4.0 - Year 2018

Mercedes-Benz do Brasil pioneered the use of the Industry 4.0 concept at its plant, located in ABC Paulista in São Paulo. The new truck and cabin production lines are structured within the pillars of the 4th Industrial Revolution, adding digital technology, the internet of things, hyperconnectivity and cloud data to the daily work of employees (INDUSTRY 4.0, 2019).

In addition to these technologies, other innovations are part of this new era of Mercedes-Benz do Brasil. Data generated by equipment such as electronic tightening machines and AGVs (Automatic Guided Vehicles) are stored in a Data Center and feed artificial intelligence and Big Data systems. Using Analytics resources, it is possible to monitor the quality of all products, detect faults and even correlate them with Sales information, making the production mix more flexible (INDUSTRY 4.0, 2019).

All these changes in the production system generated a change in the consumption of electrical energy in the production line, which is shown in table 3.

Table 3

Annual control of electricity consumption in truck assembly.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Consumo Específico (MWh/Veic)	0.59	0.64	0.52	0.51	0.60	0.52	0.61	0.66	0.83	0.49	0.49	0.42	0.49	0.35	0.32

Before Industry 4.0 After Industry 4.0

Source: (VICENTE, 2024)

It can be seen that after the implementation of Industry 4.0 technologies in the truck production line in 2018, in Table 3 we can see that the energy expenditure in the production of a vehicle unit begins to decrease in 2019, 2021 and 2022. In 2020 there was an increase in energy expenditure in the production of vehicle units, due to the low production of vehicles, which leads to a decrease in the energy efficiency of production, however it remained at the same energy expenditure as in 2018, which was the beginning of the use of Industry 4.0 technologies.

With the company's consent, the publication of data regarding energy expenditure achieved in the first two years of production of the truck line already using Industry 4.0 technologies was released, which were, (VICENTE, 2024):

- Consumption in MWh spent on assembling trucks in 2019 - 18,450.25 MWh/year);
- Consumption in MWh spent on assembling trucks in 2020 - 15,934.76 MWh/year);

It was found that after the implementation of Industry 4.0 in the assembly of trucks, it was possible to reduce the consumption of electrical energy in the process from one year to the next by 2,515.49 MWh/year (VICENTE, 2024). With the savings of 2,515.49 MWh/year, it was also possible to reduce the amounts spent on the annual energy bill, calculated as follows:

Monetary savings in reais = R$123.53 X 2,515.49 MWh = R$310,738.48 or US$62,147.70 (VICENTE, 2024).

Therefore, in 2020, the company achieved savings in its Truck Factory Project 4.0, approximately 2,515.49 MWh per year, which represents savings of R$ 310,738.48 or US$ 62,147.69 (VICENTE, 2024).

3.2.3 Bus Factory Project 4.0 - Year 2019

On the day it completed 64 years of activities in the country, Mercedes-Benz do Brasil inaugurated its new 4.0 Bus Chassis Production line.

3D and virtual simulation technologies were great allies throughout the factory restructuring process, as was the case in the Trucks and Cabins areas. Digital technology, connectivity, cloud data and the Internet of Things, elements of Industry 4.0, are also becoming a reality in the new Bus Chassis line. In addition, the new Bus line features advanced technologies such as AGV (Automatic Guided Vehicle), EOM (Electrical Overhead Monorail, an overhead transport system), automatic elevators, robotic cells, electronic tightening machines, Wi-Fi part calls and wide-screen touch screen monitors (INDUSTRY 4.0, 2020).

Data generated by equipment such as electronic clamping machines and AGVs, for example, are stored in a Data Center and feed artificial intelligence and Big Data systems. Using Analytics resources, it is possible to monitor the quality of all products, detect faults and even correlate them with Sales information, making the production mix more flexible.

All these changes in the production system, which was adapted to Industry 4.0 technologies, generated a change in the consumption of electrical energy in the production line, demonstrated in Table 4.

Table 4

Annual control of electricity consumption in bus assembly.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Specific Consumption (MWh/Veic)	0.04	0.10	0.11	0.12	0.16	0.11	0.13	0.15	0.21	0.17	0.16	0.10	0.12	0.07	0.08

Before Industry 4.0 After Industry 4.0

Source: (VICENTE,2024)

It can be seen that after the implementation of Industry 4.0 technologies in the bus chassis production line in 2020, in Table 4 we can see that the electricity consumption in the production of a vehicle unit begins to decrease in 2021 and 2022.

With the company's consent, the publication of data regarding energy expenditure achieved in the first years of production of the bus chassis line using Industry 4.0 technologies was released, compared to the previous year without the technology implemented, which were (VICENTE, 2024):

- Consumption in MWh spent on assembling buses in 2019 - 4,634.83 MWh/year);
- Consumption in MWh spent on assembling buses in 2020 - 3,870.16 MWh/year);

It was found that after the implementation of Industry 4.0 in the assembly of buses, it was possible to reduce the consumption of electrical energy in the process from one year to the next by 764.67 MWh/year (VICENTE, 2024).

With savings of 764.67 MWh/year, it was also possible to reduce the amounts spent on the annual energy bill, calculated as follows:

Monetary savings in reais = R$123.53 X 764.67 MWh/year = R$94,459.68 or US$18,891.93 (VICENTE, 2024).

Therefore, in 2020, the company achieved savings in its Bus Factory Project 4.0, approximately 764.67 MWh per year, which represents savings of R$94,459.68 or US$18,891.93 (VICENTE, 2024).

3.2.3 Results achieved with Industry 4.0 technologies

In table 5 shown below, we can see the values that were achieved with each project carried out, already using Industry 4.0 technologies by the company.

Table 5

Results obtained with Energy Efficiency Projects carried out with Industry 4.0 technologies.

Savings in Electricity Consumption	MWh	R$ thousand US$
Lighting Project with LED Lamps.	8,640	R$ 1,067,299.20 US$ 213,459.84
Truck Factory 4.0 Project.	2,515	R$ 310,738.48 US$ 62,147.70
Bus Factory 4.0 Project.	764	R$ 94,459.68 US$ 18,891.93
TOTAL	**11,919**	**R$1,472,497.36 US$ 294,499.47**

Source: (VICENTE,2024).

Therefore, through table 5, it can be seen that the company obtained a final total saving in its energy efficiency projects using the Industry 4.0 technologies presented in the work, of approximately 11,919 MWh per year, which represents a saving of R$1,472,497.36 or US$294,499.47 per year.

3.3 COMPARISON OF RESULTS OBTAINED FROM PROJECTS

One of the premises of this work is to verify the results obtained in each project analyzed, and compare the technologies used to obtain them.

Table 6

Comparison of results obtained with Energy Efficiency Projects

Technology Type	Year	Project Description	Result Obtained MWh / Year	Result Obtained R$ / Year US$ / Year	Implementation Time	Data Confidence	Monitoring of the Data
Conventional -Awareness Lectures Routine Maintenance	2015	Compressed air losses	1,000	R$ 123,530.00 US$ 24,706.00	12 months	Low	Does not exist
Conventional -Awareness Lectures Routine Maintenance	22015	Provision of other utilities	1,000	R$ 123,530.00 US$ 24,706.00	12 months	Low	Does not exist
Conventional -Awareness Lectures Routine Maintenance	22015	Production (Machinery and Equipment)	6,000	R$ 741,180.00 US$ 148,236.00	12 months	Low	Does not exist
Conventional -Awareness Lectures Routine Maintenance	22015	Lighting Systems	650	R$ 80,294.50 US$ 16,058.9	12 months	Low	Does not exist
TOTAL BEFORE 4.0			**8,650**	**R$ 1,068,534.50 US$ 213,706.9**			
Industry 4.0 - Iot, Big Data and Machine Learning.	2017	Lighting Project with LED Lamps.	8,640	R$ 1,067,299.20 US$ 213,459.84	18 months	High	Specific Software
Industry 4.0 - Iot, Big Data and Machine Learning.	2018	Truck Factory 4.0 Project.	2,515	R$ 310,738.48 US$ 62,147.70	12 months	High	Specific Software
Industry 4.0 - Iot, Big Data and Machine Learning.	2019	Bus Factory 4.0 Project.	764	R$ 94,459.68 US$ 18,891.93	12 months	High	Specific Software
TOTAL AFTER 4.0			**11,919**	**R$1,472,497.36 US$ 294,499.47**			

Source: (VICENTE, 2024)

Table 6 shows that the projects that took place in 2015 achieved energy efficiency in their actions, and with this improvement in energy efficiency, there was also monetary savings. The implementation of these projects took a long time and low cost, however, they were

projects that used conventional technologies that were aimed only at raising awareness among the public that used the environments, machines and equipment that year, without any continuity of the actions. The data obtained in the project were from individual controls, which provides a level of confidence below their representativeness. And after the end of these projects, there was no more monitoring of the data generated by the processes in other years, so it is not possible to say whether the results obtained were maintained.

In the LED Lighting Project, which took place in 2017, the implementation time was longer than in 2015 (approximately 18 months), and its cost was higher than in 2015 projects, but its gain in energy and monetary efficiency was very high, even in relation to the results that the factory itself predicted. Since it is a new material technology (LED), these gains will last for many years, not to mention that the reliability of the data and monitoring carried out by software and other concepts of Industry 4.0, allow for safer improvement actions and more accurate prediction of future changes.

The Truck Factory 4.0 and Bus Factory 4.0 Projects, which took place in approximately 2018 and 2019, had a similar implementation time (approximately 12 months). The implementation costs of these projects were high compared to the LED Lighting Project, as it was necessary to remodel the production lines to insert Industry 4.0 technologies, and maintain the factory production in parallel until the completion of the renovation of the new lines. The gain in energy efficiency was significant in production per unit, and this gain is expected to increase, as the company's production has not been high since the implementation of these projects due to the retraction of the national market for heavy vehicles, and with the increase in production, this gain in energy efficiency tends to increase, also generating greater economic gain. The concepts and technologies of Industry 4.0 were well assimilated and used in both projects, which guarantees the possibility of the gains obtained lasting for many years, as the reliability of the data and monitoring carried out by the software allow for safer improvement actions, with more accurate predictions for possible changes in the future.

4 CONCLUSIONS

Through the projects and data analyzed in this work, it can be concluded that, before the technologies and concepts of Industry 4.0, there were actions that aimed to improve the energy efficiency of industrial processes, and with their action there was a monetary gain with this reduction. However, these projects always aimed at raising awareness, and despite the quick implementation time, they did not have continuity within the processes and ceased to exist in

the future, which does not guarantee the achievement of the same results achieved in the year of implementation in the following years.

Projects that use Industry 4.0 concepts and technologies take longer to implement, cost relatively more than previous projects for their implementation, but have a greater result in the processes where they are introduced, and due to the characteristics of the technologies and knowledge of Industry 4.0, monitoring is more effective and easy to access, which guarantees greater efficiency in the control and maintenance of the results obtained.

In projects that were analyzed without the concepts of Industry 4.0, the data obtained were through individual control, carried out by people inherent to the process, which significantly reduces confidence in obtaining the values.

In projects that already use Industry 4.0 concepts, the data was obtained by real-time monitoring software, which stores the data on servers for future consultation if necessary, which significantly increases the reliability and value of the data obtained.

It is concluded that the concepts and technologies of Industry 4.0 have come to establish themselves in the industry, and if applied correctly, it will greatly facilitate the control and monitoring of processes, not to mention that it will help in predicting future actions when necessary with greater precision.

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