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Use Case on Environmental Impact Assessment in the Fish Canning Industry

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Abstract

This paper covers the environmental impact of manufacturing industrial production processes for addressing the Sustainability dimension of Industry 5.0. The model implemented by the GOGreen solution – an AI based software solution for the calculation and monitoring of the food waste and carbon and water footprints - integrated in the European Connected Factory Platform for Agile Manufacturing (EFPF), is presented as an enabler to support the environmental impact assessment in industrial SMEs. The requirements to be fulfilled by the overall system are presented together with the architecture of the integrated solution. As a use case, its implementation in a fish canning industrial process is presented to provide an exemplary scenario illustrating the process workflow and the role of the solution. The main goal of this paper is empowering non-professional users to perform the assessment of the environmental impact of their industrial processes, which is indeed a capability key in Industry 4.0 and will be even more relevant in Industry 5.0.

Keywords: Industry 5.0; Ecological transition; Environmental sustainability; Energy savings; Greenhouse gas emissions; Carbon footprint; Water footprint; Food waste

1. Introduction

Industrial companies are aware about the need to reduce the gas emissions and the water footprint of their processes. If the current rate of emissions continues, temperatures will continue to rise to levels that threaten lives and livelihoods of people everywhere (United Nations News 2020). Moreover, climate change can have impacts on human society and biology acting jointly with other environmental changes and influencing processes such as the productivity of the food-producing systems. The increased overall economic activity – induced by the increase in the average amount of energy used – has caused commensurate increases in stresses on the environment, including via the release of additional greenhouse gases into the atmosphere (McMichael, A. J. 2011). Regarding the fishing sector, new evidence continues to support a climate-induced redistribution of benefits and losses partly resulting from species and ecosystem range shifts and changes in primary productivity (Weatherdon, L. 2016). Based on the current globally interconnected fishing industry, the travel to distant reaches of the oceans for capture and the subsequent transport to the market, can require from hundreds to thousands of miles of travel by sea and air. Furthermore, refrigeration of seafood products

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is generally required at all stages of the journey from ocean to consumer, what results in substantial energy expenditure (Madin, E. 2015).

For this reason, a growing number of countries are making commitments to achieve carbon neutrality, or "net zero" emissions within the next few decades. Indeed, the Paris Agreement on climate change, calls for keeping the global temperature to 1.5°C above pre-industrial era levels (United Nations News 2020). The environmental impact assessment (EIA) becomes a vital management as a mean of evaluating how specific actions affect the environment even before they are taken (Wood, C. 2002). In this regard, a follow-up approach is required in the today's heavily regulated industrial environment. The success of any development is assessed based on its result: operational environmental performance, acceptance by stakeholders, its contribution to sustainable development and scale of the impact over all life-cycle phases (Marshall R. 2005).

Currently companies face difficulties in measuring their footprint accurately. This precision depends on a proper collection and analysis of data and emission factors that they usually do not perform on a regular basis. For that reason, the development of supporting tools to achieve a zero-emission objective or at least reduce them as much as possible is a need. The integration of environmental-related solutions in collaborative platforms supporting factory connectivity through IoT is a great opportunity for industrial companies to improve its environmental objectives, empowering them to start their net-zero journeys.

Although circular economy strategies are already underway in many companies, it is difficult for these initiatives to permeate the market. In addition, the sector needs to face the challenge of shifting from a linear to a circular economy paradigm, whose main objective is maximizing production through the valorisation of waste. The use of processing techniques with low environmental impact, the reduction of residues from packaging, the valorisation of wastewater and the accomplishment of the zero biological waste objectives should be considered to achieve a successful circular economy implementation.

The fish processing generates between 35% and 40% of edible meat, while the remaining non-edible percentage are bones, skin/scales, swim bladders, intestines, roes, liver, and blood among others. Furthermore, the demand of special products (i.e.: skinless, boneless fillets) increases the amount of waste generated. In this regard, the fish canning industry has enormous room for improvement, so many fish parts that could be revalorised to produce new products are often discarded (Cortés, A. et al. 2021). The dumping of by-products results in both the loss of large amount of bioactive rich materials and pollution problems. Therefore, the recycling of these by-products into marketable products becomes a solid waste management strategy. The treated fish waste can be used for human consumption (mince, roe, fish heads, nutraceuticals), agricultural-related uses (fish hydrolysate, fertilizer, compost) and non-nutritional uses (biodiesel and fuel, chitin and chitosan, carotenoids pigments, leather, and gelatine) (Kumar, V. et al. 2022). Besides this, in-depth description of the environmental impact assessment and sustainability issues in the fish processing industry have been carried out in previous researches (Hall, G.M., 2010) also especially focusing on the carbon footprint of fisheries (Gabrielii, C.H. 2020).

The present work aims to demonstrate that it is possible to use the environmental indicators, such as greenhouse gases (GHG) emissions and the Food Loss and Waste

(FLW) of a fish canning industry as reference indexes (or benchmarks) in the improvement of processes resulting in a better use of natural resources in the production activities with the support of friendly software applications the use of which can be done by non-experts in sustainability assessment.

The presented use case describes the use of a solution to quantify the impact of the production process of a fish canning company. This can be considered as a medium complexity industrial process that can become a potential beneficiary of the use of these solutions oriented to the reduction of the environmental impact. The relevance of this use case does not lie in the environmental impact calculation itself but in the method used to reduce such impact, which is based on a digital system that simulates industrial processes to determine the point where the highest impact and waste are generated.

In this document, an overall analysis of the state-of-the-art regarding the current impact assessment tools in manufacturing industry is presented first. Then, the selected methodology is explained considering the proposed use case as backbone. After this, the main findings obtained are described and the most relevant insights and the future work to be conducted to improve this methodology is defined.

The main objective of this paper is to empower non-expert users to perform an environmental impact analysis of the industrial processes of their company. This has been motivated on the one hand by defining a set of requirements that any integral impact assessment solution should cover. On the other hand, this has been also done by illustrating the deployment of the solution in an exemplary production line, later emphasizing the challenges that companies may find.

2. State of the Art of the Impact Assessment in Production Environments

Industry 4.0 moved producers from physical systems to a mix between cyber and physical systems, communicating with each other via the Internet of Things (IoT). This communication together with data manipulation allows industrial companies to become adaptive, intelligent, and flexible. However, the methods used to measure the industrial output have remained the same since the first Industrial Revolution. As well as the issue of turning toward a more customizable and personalized human-centred approach, another key topic in Industry 5.0 is sustainability. In the industrial environment, to be sustainable involves intangible measurements related to (United Nations News 2020) the environment, (Sharp, N. 2021) the society and (European Commission 2022) the fundamental human rights. Regarding sustainability, the industry needs to develop circular processes that reuse, repurpose, and recycle resources, while the environmental impacts need to be reduced. The manufacturers can harness the power of technologies such as AI and additive manufacturing to increase personalization, optimizing resource-efficiency and minimizing waste (Sharp, N. 2021). Moreover, the expenditure on fuels consumed by fishing fleets becomes particularly relevant. In this regard an example of efficiency perspective is that the energy content of the fuel burned by global fisheries is more much greater than the edible-protein energy content of the resulting catch (Tyedmers, P., 2005). Impact assessment tools can be used to calculate, simulate, and predict emissions of processes to reduce carbon and water footprint enabling corrective actions to improve the environmental impact indicators. The activities performed in the industrial ecosystem play an important role in the economic well-being of Europe, contributing to sustainable growth but also have a significant impact on the environment, such as gas emissions, pollutants to water and soil emissions and generation of waste and use of energy. In this sense, several environmental policy instruments, ranging from mandatory rules to voluntary tools, intend to ensure that European industry works towards a high level of environmental protection, minimizing its environmental footprint and increasing its sustainability (European Commission 2022).

Furthermore, the emission trading system in the European Union launched on January 1, 2005, operates because of a maximum limit of greenhouse gases that can emit the facilities, which are being reduced over time to achieve the emission reduction targets established. Within these limits, the facilities can receive or buy and sell emission rights according to their needs. They can also purchase certain limited amounts of international credits from emission reduction projects around the world, as the import of CO_2 emission rights (EU ETS 2022).

Much research has been done regarding the environmental impact assessment in particular industries. In the building industry, the environmental assessment tools vary to a great extent, depending on components, whole buildings, and assessment frameworks. These tools cover different phases of the life cycle of a building considering geographical scopes (Haapio, A., Viitaniemi, P. 2008). Also, the packaging industry takes advantage from software tools available in the market in order to compare different packaging options in terms of design and sustainability aspects (Speck, R. et al. 2015). Even in fruit production, where the application of environmental indicators is not widely extended, an effort has been done to converge in a common approach to handle the impact of this industry. Considering environmental assessment methods among them, the ecological footprint analysis can be found (Cerutti, A.K. et al. 2021).

Several software tools have been developed for long time for both data processing and simulation and analysis of environmental problems. These tools need to cover both data and numerical models as well as appropriate user interfaces to visualize the results and enables an interactive control of the software. The integration of geographical information systems and the use of Artificial Intelligence (AI) components allow an efficient behaviour of the system (Fedra, K. 1990). In this regard, the AI is offering important benefits for organizations in terms of reducing greenhouse gas (GHG) emissions, efficiency, and waste reduction. AI can help through:

- **Automation and Monitoring**: AI-powered data engineering to automatically track emissions across the carbon footprint (i.e.: operations data, corporate travel, IT equipment, materials, components, and suppliers). For the present work, data processing has been carried out for alert management, using machine learning with anomaly detection algorithms such as Isolation Forest (Scikit Learn: Isolation Forest 2021) and Local Outlier Factor (Scikit Learn: LOF 2021). Moreover, work on pattern detection through clustering techniques such as K-means has also been done.
- **Prediction**: by forecasting future emissions through a company's carbon footprint, relative to current reduction efforts, new carbon reduction methodologies, and future demand. For this, ARIMA models, linear regression, Random Forest (Scikit Learn: Random Forest Regressor 2021) and XGBoost (XGBoost 2021) has been applied.
- **Reduction**: the company can more accurately set, adjust, and achieve reduction targets.

For such purpose, metaheuristic algorithms for optimization problems such genetic algorithms and/or evolutionary algorithms has been considered.
The calculation of the **Carbon Footprint (CF)** is one of the current tools used to measure the environmental impact of economic and productive activities. Until now, this calculation had a voluntary nature, but the legislation is aimed at making this calculation mandatory in the future. The CF of an organization is the totality of greenhouse gases (GHGs) emitted by direct or indirect effect through the activity carried out by it (MITECO 2022). To calculate the CF, three types of emissions are differentiated:
- **Scope 1**, which covers direct emissions from own or controlled sources.
- **Scope 2**, which covers indirect emissions from the generation of electricity, steam, heating, and cooling purchased and consumed by the company.
- **Scope 3**, which includes all other indirect emissions that occur in a company's value chain. It is often the largest scope and hardest to quantify.

The CF is calculated by multiplying the Activity Data by its corresponding Emission Factor. Activity Data is the parameter that defines the level of activity that generates GHG emissions, and the Emission Factor is the amount of GHGs emitted for each unit of the "activity data" parameter.
$CF = Activity\ Data\ x\ Emission\ Factor$
Based on this formula there are several methodologies for calculating the carbon footprint (UNE-ISO 14064 (AENOR 2019), GHG Protocol (World Resources Institute 2004), etc.).
To help companies with the calculation of the CF, there are plenty of (free) tools and service providers available. But a good and trusted CF still has many challenges. The main issues for CFs are:
- Inconsistency with methodology.
- Incomplete Scope (mostly missing Scope 3 categories).
- Lack of necessary aggregation for further use (e.g., Disclosure Insight Action (CDP Europe 2022), SBTs (SBTi 2022), certification, etc.).

Water footprint (WF) is together with CF, another important environmental indicator that measures the volume of fresh water (in litters or cubic meters) used throughout the entire production chain of a consumer item or service. The WF is made up of three things depending on where the water comes from, according to Water Footprint Network (Water Footprint Network 2022):
- **Green water footprint** is water from precipitation (rain or snow) that is stored in the root zone of the soil and evaporated, transpired, or incorporated by plants.
- **Blue water footprint** is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product, or tipped into the sea.
- **Grey water footprint** is the amount of fresh water required to assimilate pollutants in the production process to meet water quality standards.

It should be noted that, by scoring companies and cities, Disclosure Insight Action (CDP) aims to incentivize and guide them on a journey through disclosure towards becoming a leader on environmental transparency and action. On the other hand, the Science Based Targets initiative (SBTi) drives ambitious climate action in the private sector by enabling companies to set science-based emissions reduction targets.
Currently there is a surprising lack of empirical research on how companies assess and

forecast the environmental impact of their new circular business models. The way companies use the environmental impact assessment methods during the business model experimentation process is many times unclear. The tools commonly used by practitioners for impact measurement are 'rules of thumb', what refers to the designing of new ideas based on internal guidelines related to circular design principles or using technology to conduct technical measurements of their environmental impact. Most common barriers in environmental impact assessment are:

- **Lack of enough data**: lack of reliable and/or accessible data sources)
- **Uncertainty during experimentation**: companies often must make a lot of assumptions and generalizations, hindering the quantification of the environmental impact of all parts of their business
- **Lack of knowledge**: what leads to the inability to comprehensively measure the current environmental impact, preventing designers and business developers from incorporating lower impact choices

Companies show a high desirability to track environmental impact. However, small companies tend to give a lower priority to this measurement compared to large corporates. This may be justified due to the lack of resources, time, and the complex nature of environmental impact assessment. But besides this, the results from such assessments often do not lead to specific improvements performed. The knowledge for measuring the environmental impact tends to be concentrated in a few experts within the company, who are, in most of the cases, are not the product or business model designers (Das, A. et al. 2021).

Consulting companies providing services to industries for implementing measures for the elaboration of the CF and the WF as separated services, as well as designing improvement plans can be actually found in the market. Some of these companies usually operate through spreadsheets or calculation software not accessible to customers. Others, integrate automation options only for data collection but not quantification of emissions. Many companies offer the CF calculation service while the WF calculation has a lesser presence in the market. Furthermore, most companies offering these services do not offer certifications of environmental impact.

The current work covers the use of an exemplary solution to calculate both CF and WF in a simple way targeting non-expert users at industrial SMEs, retrieving the environmental footprint, and providing the simulation of the potential impact. The aim at this point is to motivate both the developers to implement user-friendly tools to measure the environmental impact of manufacturing processes increasing the user-friendliness as well as the industrial actors to take advantage of them to manage the reduction of footprints and emissions.

3. Methodology

The use case scenario is briefly presented to provide a comprehensive walkthrough of the methodology involved in the whole process. Then the user requirements for the overall solution are introduced together with the integration process. This solution used GOGreen software by AI TALENTUM, an AI based web platform for the calculation and monitoring of food waste and the carbon and water footprints, that simplifies such calculations to the users enabling on the one hand the management and control, and on the other hand the analysis and prediction.

3.1 Presented scenario and hypothesis

In order to illustrate the quantification of the environmental impact in an industrial environment, the canning process of a recognized Portuguese tinned fish (sardine and tuna) producer based on Porto was selected, taking its production data as main dataset. Data retrieved mainly consisted of time series from collected and measured variables (weight, temperature, energy and water consumption, tons of raw materials, waste, and final product) at main stages: reception, defrosting, cutting, cooking, and canning (Fig 1.).

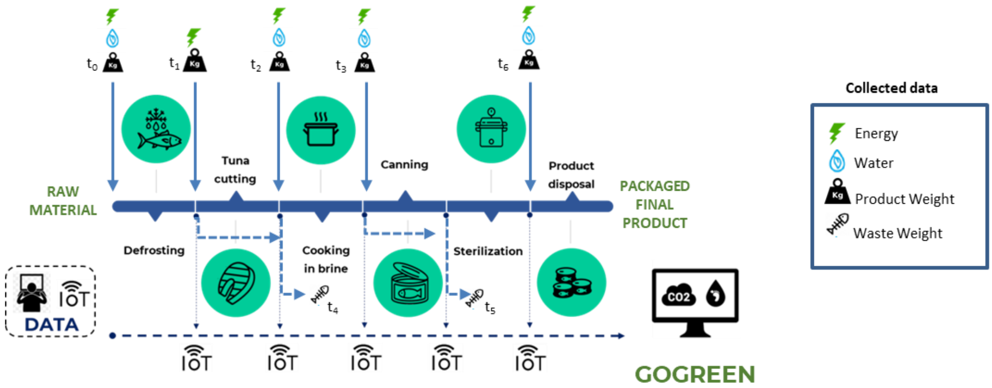

Figure 1: Flow chart of the fish canning process emphasizing the key point for data collection.

3.2 Applied method

The presented work was organized in different stages in order to make the impact assessment calculation in industry environments accessible to non-experts on this matter. First, requirements for the whole solution were collected from functional, non-functional, and user interface requirements. Then, the tool was integrated in a federated platform to extend it with interoperability facilities within an industrial ecosystem. Finally, the developed use case presents the scenario that leads to later report how the availability of this integrated solution supports companies to both reduce the footprint caused by their production processes and consumption of own resources.

A set of functional (activities the system must support) and non-functional (operational features) requirements was defined. Besides this, particular emphasis was placed on user interface requirements. Functional requirements define those fundamental actions that the system must consider when the information is received and processed, and results are produced. These are:

- **Management of users, companies, and locations**: The system must allow the addition and update of users, companies, and locations for each company.
- **Data input**: The system must allow the definition of processes and factors with amounts.
- **Calculation of water and carbon footprint**: The system should send the provided

process information to an external API to get the calculation.
- **Platform login**: Users should be able to log in the collaborative platform through unique user accounts.
- **Visualization of results**: Users should be able to visualize the calculated footprints of a series of processes, grouping by scope.
- **Database saving and Blockchain**: Export of calculated results to database with optional Blockchain support should be available for later reference.
- **Sensors at shop floor**: The system must allow the integration of IoT devices installed in production plant, providing the necessary input data for calculations.
- **Footprint reports**: The system must allow the generation of reports based on calculated water and carbon footprints.
- **Simulation**: The system must allow the execution of simulations based on prefixed setups.

Non-functional requirements were detected. These requirements set the expected quality attribute of the implemented system. In this regard, the solution just involved regular security issues such as firewall and backup management. Requirements for communication interfaces were also defined. HTTPS protocols were used to call the calculation and storage APIs provided by GOGreen, as well as interacting with Grafana (Grafana 2022), that provided a flexible dashboard solution to query and visualize data.

The graphical user interface (GUI) had to represent the functionalities of the system in a clear manner in order users could simplify their tasks. The most important requirements in this regard are:
- **Simplicity**: Unnecessary design elements will be avoided, selecting simple and easy-to-understand designations.
- **Goal-oriented design**: Sections must be well structured while elements must represent its function in a clear manner.
- **Consistency**: All individual components should be consistent with each other when multiple elements and graphics are used.
- **Design:** Units, colours and text should highlight or hide the element depending on the purpose of the component. Appropriate fonts and sizes should be used accordingly.

GOGreen allows users to get instant calculations of the CF and WF, in a very simple way, using a single software tool. It not only accurately measures emissions directly produced by the company's own activities (Scopes 1 and 2 mentioned in chapter 2) but it also quantifies the more difficult-to-measure, indirect emissions produced along the company's entire value chain (Scope 3) since for many companies the majority of their GHG emissions and cost-cutting opportunities lie outside of their own operations. GOGreen offers an accurate baseline of the company's current environmental footprint and allows simulating the potential impact of abatement activities and automatically recommends the best abatement options. The implementation of Blockchain technology to certify the environmental impact reinforces the use of the tool for the certification of the CF and WF, giving companies and integrated alternative to for certification without the need of subcontracting additional services. The tool also includes an economic module for the assessment on the level of investment required according to the current carbon credit prices to achieve carbon neutrality. In addition, there is the treatment that GOGreen makes of the emission factors from the point of view of allowing the conversion between

the activity data and the GHGs emission data. For this, it uses not only international standards, but its own formulas and conversion factors which have been validated and calculated in companies in the sector.
In general, the environmental impacts of GHG emissions are especially influenced by the consumption of certain resources (water, electricity) and by the specific raw materials used in the production processes of each company (for this use case: tuna, oil, salt, …).
EFPF is a federated smart factory ecosystem and digital platform that connects stakeholders in the digital manufacturing domain. This platform brings innovative functionalities so the users can experiment with disruptive approaches as well as implement solutions for interoperability, connectivity, and supply chain efficiency (EFPF 2022). The integration of an environmental impact assessment solution in a federated platform such as EFPF would imply the use of the following components:
- **API Security Gateway**: for accessing other EFPF services.
- **TSMatch Gateway**: for factory connectivity components.
- **Blockchain extension**: for the certification and verification of the environmental impact.
- **EFPF Security Portal**: for single-sign-on (SSO) and management of user roles.
- **EFPF Marketplace**: for making the solution available to all users in the environment.
- **EFPF SDK**: for the implementation of the front-end.

The adoption or not of these components depend on needs and requirements of each scenario. GOGreen would not require the use of the EFPF SDK so, even if a new user interface has been implemented, this is based on a previous version of the tool.
As shown below in Fig. 2, the GOGreen solution is contained in an EFPF portal application at user interface level. Users authenticate through the EFPF Security Portal, based on Keycloak, an open-source identity and access management solution for applications and services (coMakeIT 2022). External login and user registration can also be done through the Keycloak API. The calculations are done by the GOGreen tool which also provides an API (IOTIC Solutions 2021) that enables to retrieve the results.

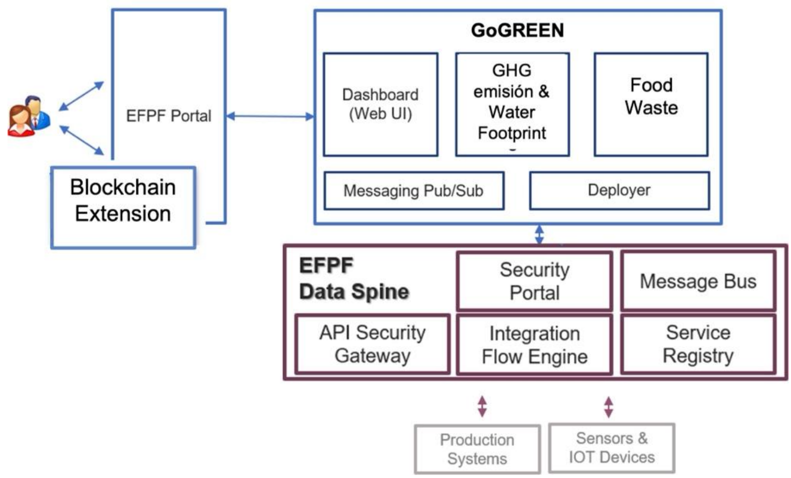

Figure 2: Overall architecture of the GOGreen solution once integrated in the EFPF platform.

3.3 Use case experimentation

The quantification of environmental impacts and food waste in the fishing sector is an arduous and complex task since we must consider the different phases that occur from the capture of the fish to its consumption by the final consumer. Due to the nature of the current case study, the work was focused on the processing performed at the canning factory plant, which becomes an essential part in its production chain. Therefore, just the stages from the reception of the raw material until the packaging process were considered. The Food Loss and Waste (FLW) in wastewater was then calculated as follows:

$$FLW = Wt0 - Wt6 - Wt4 - Wt5$$

Where FLW refers to pieces of the fish that are removed or lost during the processing (head, meat pieces, bones, and skin) and do not re-enter to any other productive utilization, and Wt refers to the product weight at time "t".

The user interface of GOGreen is implemented by following a minimalistic design approach. A login access is first prompted to the user. Then, the data input section is prompted to the user and, once the data has been introduced by the user, the environmental impact report of the analysed process - which is the main information that users need to gather - is generated. The Fig. 3 shows a detail of the user interface of the tool.

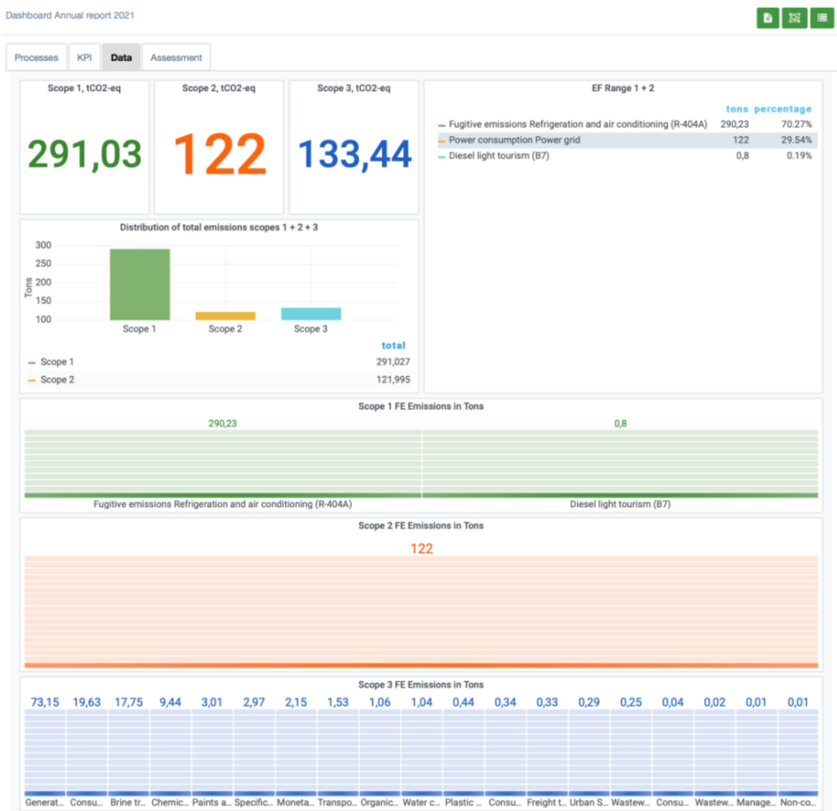

Figure 3: Detail of the dashboard view of the implemented solution.

The disaggregated data - necessary for the operation of the system - was captured daily. The data was aggregated on a weekly and monthly basis to determine the general GHG emissions and FLW predictions for the company and the contribution of each of the different stages of the process (reception, defrosting, cutting, cooking, and canning). Through these predictions, the company could estimate the annual environmental impact that its activity will have (projections) and preventively carry out the decarbonization actions that it considered most effective (purchase of products with less CF, investment in energy saving infrastructures,).

In parallel, and by comparing predictions and real data, the company would be able to continuously adjust the production processes with the information provided by the system.

4. Findings and Discussion on the Data

This chapter describes the results achieved during both the deployment of the system including the integration process, and the experimentation, as well as the interpretation and analysis of these results. Finally, the discussion section focuses on the found barriers and challenges to overcome.

According to the Survey to European food SMEs (Galindo, C. et al. 2021), the main limitations for a wider adoption of these solutions are the lack of personnel with the required digital skills in the food processing and manufacturing sector, and the difficulty in acquiring the know-how required to implement AI-based solutions. Digital-skill profiles are highly valued in the market, what hinders the food industry SMEs to recruit and retain them. In addition, many of these companies are based on rural areas with limited variety of leisure activities. All these factors make companies to avoid the adoption of AI or even outsourcing its implementation. The lack of economic resources to invest in AI solutions soon also represents another serious limiting factor for many companies. For this reason, larger funding plans at European or national level would lower the barriers for the adoption of AI.

One of the main drivers of adoption of these solutions is to grant companies access to practical environment where benefits and ROI (return on investment) can be tested or proved. This also fastens the digitalization process so companies can experience the potential of these technologies and understand how they work and how can they be applied to its processes. The spread of success cases by similar industrial partners has been also identified as a key driver for the adoption of these technologies (Galindo, C. et al. 2021).

A large proportion of companies in the EU consider that external obstacles that hinder the adoption of AI technologies are the strict standards for data exchange and the need for new laws or regulation. In addition, the lack of public or external funding and the liability for damage caused by these technologies are also relevant for industrial companies. Regarding internal barriers, the difficulty to hire new staff with the right skills, together with the cost of adoption and the lack of data available are considered the most relevant by companies (European Commission 2020).

In particular, the fish industry is facing such environmental regulations challenges and increasingly restrictive sustainability standards demanded by society. This industrial activity generates a high quantity of fish by-products and wastes, using only the 40-60% of tuna in the final canned product. Other aspects are related to the canning process such as water use. This industrial sector has an important environmental impact caused by the high-water and energy consumption and the generation of wastewater. The digitization level of these companies, where there is prevalence for maintaining manual traditional procedures becomes an extra challenge. Nevertheless, data obtained in the use case is collected through sensors installed in a test bed focused on developing a digital twin of this process.

4.1 Collected data

Depending on each deployment, data and metrics from the production line can be manually introduced in the tool or collected directly from connected devices at shopfloor. In this case data was collected from two inputs' sources: a Manufacturing Execution system (MES) and IoT sensors installed at the company's facilities for energy monitoring and water flow measurement.

With the objective of acquiring relevant production data, multiple sensors integrated with embedded devices were deployed in multiple stages of the production process. Each sensor was integrated with a Raspberry Pi 4 to be able to run scripts for the sensor data acquisition using Modbus or Serial connection, depending on the sensors' technology. Data coming from the devices was sent to an edge server where it is pre-processed and stored in a time series database. Using a MQTT endpoint implementation, interoperability with the MES was leveraged, enabling the sensor data gathering, while the MES provides specific data from the production processes. The Fig. 4 below illustrates a sample dataset of collected data.

Kafka Topics	InfluxDB Measurements	MQTT Topics	Unit	Data type
kafka_energy_tri0_active_energy_B	influx_energy_tri0_active_energy_B	energy_tri0/Active_energy_B	Wh	float
kafka_energy_tri0_active_power	influx_energy_tri0_active_power	energy_tri0/Active_power	W	float
kafka_energy_tri0_active_power_1	influx_energy_tri0_active_power_1	energy_tri0/Active_power_1	W	float
kafka_energy_tri0_active_power_2	influx_energy_tri0_active_power_2	energy_tri0/Active_power_2	W	float
kafka_energy_tri0_active_power_3	influx_energy_tri0_active_power_3	energy_tri0/Active_power_3	W	float
kafka_energy_tri0_apparent_power	influx_energy_tri0_apparent_power	energy_tri0/Apparent_power	VA	float
kafka_energy_tri0_apparent_power_1	influx_energy_tri0_apparent_power_1	energy_tri0/Apparent_power_1	VA	float
kafka_energy_tri0_apparent_power_2	influx_energy_tri0_apparent_power_2	energy_tri0/Apparent_power_2	VA	float
kafka_energy_tri0_apparent_power_3	influx_energy_tri0_apparent_power_3	energy_tri0/Apparent_power_3	VA	float
kafka_energy_tri0_current	influx_energy_tri0_current	energy_tri0/Current	A	float
kafka_energy_tri0_current1	influx_energy_tri0_current1	energy_tri0/Current1	A	float
kafka_energy_tri0_current2	influx_energy_tri0_current2	energy_tri0/Current2	A	float
kafka_energy_tri0_current3	influx_energy_tri0_current3	energy_tri0/Current3	A	float
kafka_energy_tri0_currentN	influx_energy_tri0_currentN	energy_tri0/CurrentN	A	float
kafka_energy_tri0_export_active_energy	influx_energy_tri0_export_active_energy	energy_tri0/Export_active_energy	Wh	float
kafka_energy_tri0_export_active_energy_1	influx_energy_tri0_export_active_energy_1	energy_tri0/Export_active_energy_1	Wh	float
kafka_energy_tri0_export_active_energy_2	influx_energy_tri0_export_active_energy_2	energy_tri0/Export_active_energy_2	Wh	float
kafka_energy_tri0_export_active_energy_3	influx_energy_tri0_export_active_energy_3	energy_tri0/Export_active_energy_3	Wh	float
kafka_energy_tri0_export_active_energy_P	influx_energy_tri0_export_active_energy_P	energy_tri0/Export_active_energy_P	Wh	float
kafka_energy_tri0_export_active_energy_T1	influx_energy_tri0_export_active_energy_T1	energy_tri0/Export_active_energy_T1	Wh	float
kafka_energy_tri0_export_active_energy_T1_1	influx_energy_tri0_export_active_energy_T1_1	energy_tri0/Export_active_energy_T1_1	Wh	float
kafka_energy_tri0_export_active_energy_T1_2	influx_energy_tri0_export_active_energy_T1_2	energy_tri0/Export_active_energy_T1_2	Wh	float
kafka_energy_tri0_export_active_energy_T1_3	influx_energy_tri0_export_active_energy_T1_3	energy_tri0/Export_active_energy_T1_3	Wh	float
kafka_energy_tri0_export_active_energy_T2	influx_energy_tri0_export_active_energy_T2	energy_tri0/Export_active_energy_T2	Wh	float
kafka_energy_tri0_export_active_energy_T2_1	influx_energy_tri0_export_active_energy_T2_1	energy_tri0/Export_active_energy_T2_1	Wh	float
kafka_energy_tri0_export_active_energy_T2_2	influx_energy_tri0_export_active_energy_T2_2	energy_tri0/Export_active_energy_T2_2	Wh	float
kafka_energy_tri0_export_active_energy_T2_3	influx_energy_tri0_export_active_energy_T2_3	energy_tri0/Export_active_energy_T2_3	Wh	float

Figure 4: Sample of data subset.

4.2 Analysis of data

For this use case, historical data provided by the company for the 2019 and 2020 campaigns were analysed. Likewise, the data recorded by the system for the year 2021 were considered. All these data were processed monthly and taking into account the seasonality of production, in which there were months with canning production and months with only maintenance of the facilities. These data were treated by homogenization and

characterization techniques with the methods described in Chapter II. The gathered results enabled to represent the behaviour of the typical fish canning process in a SME of this sector in a monthly and yearly basis as well as by aggregation.
The results obtained by the prediction systems were contrasted with the observations and evaluations that, in a timely and periodic basis, the company performed on the control of energy consumption, water consumption, wastes and final product obtained. These results were incorporated into the management system of the company to improve its processes. Similarly, the results of the calculations of the environmental impact assessment served as a base for modifying the energy efficiency and decarbonisation plans implemented by the company.

5. Conclusion

In this work, the requirements of the integrated solution were analysed, and the selected use case of fish canning industry helped to better understand the needs of the system and how it is expected to operate. The most relevant limitations, concluding remarks and future work are described more in detail below. It should be noted that studies have been carried out to determine the carbon footprint of a specific part of the carbon footprint, such as the tuna (Tan, R. 2009) or produced by a concrete task, such as the transport process (Parker, R.W.R. et al. 2018) and focusing on trawl fisheries (Sala, A. et al. 2022). In this regard, there are tools of generalist purpose that allow a general estimation of the environmental impact (seafoodco2 2022). Therefore, the present study was focused on the development of a tool which, using Artificial Intelligence and making use of the calculation of carbon footprints, water footprint and food waste, enabled a digital modelling of the fish canning process.

5.1 Limitations

Besides the internal and external barriers already described in this document, like the strict standards, the low availability of skilled staff and the lack of enough funding options, the industrial culture regarding the environmental impact assessment should be considered. This assessment is regularly performed by large companies but not SMEs. The availability of doing this assessment in periods shorter than a full year becomes particularly relevant for these companies, so it enables companies to take more control of its emissions to make choices based on these calculations.

5.2 Concluding remarks

The proposed solution reports the number of tones of CO_2 and m^3 of water of the process in an easy and understanding manner. Also, the minimization of emissions and cost becomes easier through the creation of periodical reports and simulations to observe the impact of efficiency measures to reduce the environmental impact. However, besides this, the particularities of the presented model - which are briefly described below - should be considered.
The presented model enables a digital simulation of the processes in both an aggregated/disaggregated perspective and regular basis to allow companies take decisions during the day instead of taking them after a long period of assessment. This way,

companies can take control of CO_2 emissions, water usage and wastes progressively adjusting its manufacturing processes on the fly to minimize the produced environmental impact and reach the impact reduction objective.

Two main statements were demonstrated from data collected in period from March to December 2021. On the one hand, when a global and standardized measure was applied to the environmental impact evaluated in a monthly basis, the targeted actions to minimize it became more effective in comparison to a yearly basis, which is one of the most common approaches in industry. On the other hand, the influence of Scope 3, that referred to the specific processes of the fish canning industry, was difficult to assess in the absence of reliable measurements of factors used in continuous production (i.e.: oil, salt, …).

5.3 Future work

Upcoming experiments may bring extra needs and challenges to light, mainly due to the close interoperation between the host EFPF platform and GOGreen tool and the complexity of its components. However, the available documentation and technical support facilitates this process, which can be considered a comprehensive example case for industrial case aiming to take advantage of federated and interoperable platforms supporting Industry 4.0 and IoT.

In this sense, the applicability of the model implemented by GOGreen in other industrial sectors involving different processes is under consideration, in particular the agro-food industry, which shares many common features with the canned fish industry covered in this paper. The opening to heterogeneous use cases in different industrial clusters would enable the increasing of the prediction capability of the actual model, so calculated models can be better adjusted to needs.

In the light of the obtained results, the need arises to incorporate the processes before the reception of the ray material at the factory in the overall calculation. In particular, the process related to the catch, handling, and transfer of the fish from the extraction to the processing points.

Future work also considers the continuous review of the legal framework. Indeed, the entry into force of the new version of the ISO 14064 standard generates the need to modify the legal classification of the scopes 1, 2 and 3 to a new one.

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