Managers must understand that no single approach will fit the bill and leadership is required. Improvements will need to be managed in an overall pprogramme of Asset Management. However the most the most important aspect is an attitude of mind of never being satisfied with today's performance.

Finally always remember that the only customer a company has is the buyer of their manufactured products. Each person working in the organisation is contributing to the profitability of that product and the better the communication and co-operation between individuals and groups the greater the profit margin will be. That is the key to achieving the ultimate goal of staying in business.

Keep Learning and improving to achieve Excellence

TEROLOGY, 3D MODELS TO HELP DIAGNOSIS AND SUSTAINABLE FUTURE A NEW PERSPECTIVE FOR MAINTENANCE

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SUMMARY

The terology concept was introduced in 1994, with the objective to synthesize a new view of Organizations maintenance activity and reach good levels of reliability during life cycle of facilities and equipments. When this concept is implemented in a large organization it is necessary to re-equation the maintenance department, to increment its level of operation and to introduce an information system for maintenance management. After this stage, the next step is to put into operation on-condition maintenance techniques and a fault diagnosis system. For this kind of system it is proposed in the paper a new approach based on 3D models, in which a technician will be oriented not only from a sequence of a check list of procedures to correct the fault but also trough dynamic 3D illustration of all movements and their sequence, both to dismount and correct fault, but also to reposition the pieces into its correct place. This is being added to the more recent developments around on-condition of Diesel Engines and wind farms, in an integrated perspective around SMIT information system. Obviously, all these developments have in account the balance between costs and environment, but having always in mind the overwhelming costs, giving preponderance to environment. Also important is to consider that, in modern Organizations, it is important to use the state-of-art of technology but, also, it is necessary to minimize the impact over nature with the manufacturing of new goods, not only through methods but also through the reduction of its production. Humanity needs to rethink the economy and redesign it, in order to maintain and, if possible, to increment quality of life for masses, but always with the biggest possible respect by nature. Good terology management, good replacement and on-condition maintenance policies, namely the ones connected to the environment, are reasons to justify why terology is so important for a better and sustainable future. The planet, nature and the future are not sustainable if man continues destroying it to manufacture new goods that, when their life ends, are destroyed, rarely recycled, reused or doing nothing, but always with big consumption of energy and, many times, adding new not organic materials. To have sustainability it is necessary to preserve, to increment life cycle of goods, to reuse, to implement renewal policies, to return to nature what is possible, with the objective to live together, humanity-nature and technology, in a friendly manner.

Key Words: Terology; Maintenance management; Predictive maintenance; Sustainability; 3D models

1 INTRODUCTION

Terology is defined as the combined use of operational research techniques, information management and engineering, with the objective of accompanying the life cycle of facilities and equipments; it includes the definition of specifications of purchase, installation and deliviring, and also the management and control of its maintenance, modification and replacement and close monitoring in service too [1]. Better maintenance, aided by information systems, helps to increase the life cycle of facilities and equipment and to reduce emissions and consumption of energy. These are only some reasons that point out to our understanding that maintenance or, by other words, terology helps the environment. The work developed along more than one decade started with information systems, and continued through fault diagnosis, on-condition maintenance of diesel engines and wind generators, and ought to continue adding knowledge pieces like these, around the maintenance understanding that the author called terology [2] [3]. This is the reason why this paper presents a new piece of the big jigsaw that is Terology supported by the information system called SMIT (Integrated Modular System for Terology). The new module refers to the use of 3D models for Maintenance Objects to help the fault diagnosis module, which is the last scientific value added to the team that subscribed this paper. Economic recession, environment degradation and the imminent catastrophic disorder of the planet are enough real reasons to see maintenance with new eyes, as a way to minimize the impact of humans over nature, through less effluent emissions and redesigning current facilities and equipments with the objective of not taking more resources from nature, and to help to maintain the same, or give more quality of life for everyone. This is the real challenge that must be reached. Economy has

to be redesigned having always present the new ecologic concept that will permit humans to live in harmony with nature, preserving it and returning what it gave us and we transformed but, after had been used, extensively, with no aggression, we return in an ecologic way. Terology has the potential to help manage goods developed by humans in a better way, minimizing or, at least, turning null the effects of those goods over nature and, it is because of this, that we believe terology can give a contribution for a sustainable future.

2 MAINTENANCE VERSUS PRODUCTION

The economy and well being of the 19th and 20th centuries were supported by intensive consumption of natural resources. These were of all types, namely, forest, minerals and fossil resources. The result of this way to manage nature with the objective of creating new goods for well being was the degradation of the planet in several manners, like the following:

- Humans took resources from the interior and surface of earth;
- Humans transform natural resources into artificial goods, using energy initially from forest and coal and, nowadays, from petroleum and gas;
- Functioning of many goods consumes a lot of energy;
- As the heat cannot be sent outside of earth's atmosphere, it causes the planet to become more and more heated, like a sauna;
- Additionally, and no less important, the artificial goods send a lot of chemical products to the atmosphere and to the surface and interior of earth, globally contaminating the planet;
- Also important are the wars, forest fires, among other accidents that destroy and degrade the planet.

All this degradation was possible, because the evolution of knowledge was *exponential* and this has been the *bible* of humanity. Science always believed that humanity could manage, control and always find solutions for all of nature's problems. The results that we are feeling in our lives show that it was not humans that dominated nature but that humans are ill, like our planet, by the inadequate use of knowledge and, finally, it will be nature winning the war!

The main objective of all kinds of production is to be effective or, at minimum, efficient. This means that the objective is to take more and more from earth, from sea, from any place where natural resources exist and can be value-added in commercial terms. The main objective seems to empty all resources, so efficient possible but... if appears the danger of really empty a certain resource than, it is easy to make a natural park or a bank of seeds or something similar, believing that in a uncertain day in the future that resource will be rehabilitated. But, if this is bad enough, people don't care if some animals and plants species disappear. Where does maintenance enter here?

Maintenance has been seen as a way to help to maintain production as high as possible. But, by this way, it is seen as a cost that, by consequence, diminishes the profits of companies. This implies that maintenance has been managed as an activity less important and less valuated when compared with other activities in companies, namely with production. Nevertheless, the competences and the knowledge involved in the maintenance area by technicians are very high and one of the most eclectic within a company. So why not take this potential to guarantee a better and more sustainable future? And how? Proposal for percentage inclusion of 25%(...) production VS 75%(...) maintenance in terology studies, effectively changing the negative impact of raw production and applying new ways of producing and maintaining facilities and equipments in a more plug and play, or customize and transform manner directly for the user.

Under the maintenance theme of facilities and equipment (Maintenance Objects – MO), it assumes several approaches, namely the guarantee of reliability of MO, renewal, their replacement, and all activities associated, including purchase and withdrawal; by other words, the maintenance approach of terology. But, there exists always a *but*... The economic models that are soaked within algorithms and thought in universities, have the principle that natural resources are infinite, or almost, and the life cycle of MO is seen without any importance by environment. Here lies a problem: it is necessary to change the nowadays economic paradigm for an ecologic economy paradigm. This may signify that it would be necessary to deconstruct present economy and to reconstruct it; but what is the cost of that?

The cost is, before anything, political. It is necessary to assume the cost of survival! But, it is necessary to make the change quickly but carefully in order not to make many victims. The most part of businesses are directly or indirectly dependent of petroleum, so, it is necessary to make the changes taking this into account, such as:

- Stop construction of new buildings, unless it is extremely necessary; in this case, the materials should be ecologic and new buildings are necessarily autonomous in terms of energy, water and so on;
- Adapt present buildings to be more efficient, from the point of view of energy; at least in order to reach the objective of autonomy;
- Same concept for water, namely, recycling used water and storing rain water;
- Using solar panels to heat water;
- Using and reusing ecologic bags to transport purchases and eliminate other types of plastic bags;
- Using ecologic public transportation, transforming combustion engines into ecologic ones;
- When necessary, using private transport that was transformed from combustion engines to ecologic ones;
- Buying a new car only and only when necessary and, obviously, ecologic;
- New materials will be only ecologic;
- Planting trees in cities in as many points as possible! All cities will have a well defined relation between green areas and constructed areas;
- All citizens should help government pay the changing that will be made in a well defined period of time.

As can be seen, maintenance or, by other words, terology, will be always in all points of the changing of the aspects that will make humanity believe in its future and of the planet.

3 MAINTENANCE INFORMATION SYSTEMS

The complexity and diversity of situations around the management of facilities and equipment implies the use of information systems for maintenance. The developments mentioned in this paper are supported over the SMIT that is an information system that starts with the characterization of the facilities and equipment and ends with the withdrawal of them [4], and has the following modules, figure 1, [5]: Maintenance Objects (MO); Work Orders (WO); Suppliers; Technicians; Tools; Spare Parts; Intervention Requests; Fault Diagnosis; Maintenance Plans; Withdrawal.

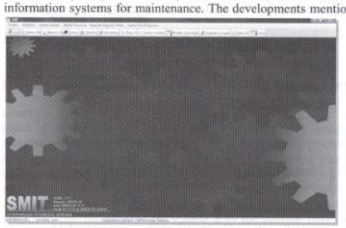

Fig. 1 – SMIT main Form

The terology activity starts with the purchase of MO and ends with the withdrawal. The modules and the interrelation among them is the following:

- The *Maintenance Objects* (MO) module permits the characterization of facilities and equipments, namely, technical, economical and reliability data;
- The *Work Orders* (WO) module permits manage each intervention, planned or non-planned through a WO and this, when closed, spreads data by several modules;
- The *Suppliers* module intervenes since the insertion of MO data and is updated with data from WO, namely economical data;
- The *Technicians* module manage the internal and external ones and is related with WO and planning modules;
- The *Tools* module, namely the special ones, is very important in certain interventions. This module manages this item that interacts with planned and non-planned maintenance;
- Each maintenance intervention, planned and non-planned, uses *Spare Parts* that have a certain cost. This module manages this item, including the ordering;
- The *Intervention Requests* module is used when there is a fault and, by consequence, it is necessary to open a WO;
- The *Fault Diagnosis* module is filled through the register of non planned interventions and, by other hand, it helps this kind of maintenance, minimizing intervention time;
- The *Maintenance Plans* is a module where the interventions are planned including the resources necessary for them;
- The *Withdrawal* module permits to evaluate the moment to replace the MO or renewal it and completes the SMIT management cycle.

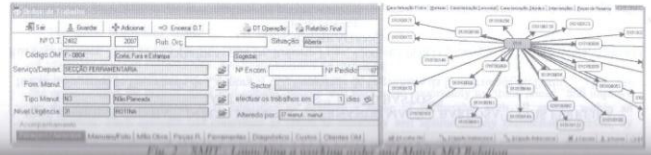

Fig. 2 – SMIT – Controlling a working order and Matrix MO Relation

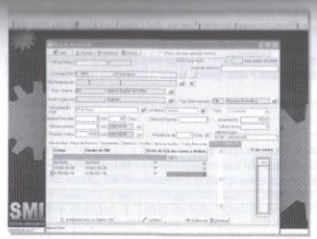

Fig. 3 – SMIT – Maintenance Plan

SMIT manages complete aspects of the terology intervention in the organization. But, one of the major potentials of this system, that make it so powerful, is its modularity, that permits to add new modules and new features easily and in complete dialogue with the existing modules. Figure 2 shows an extract of the form of the launching a WO and Matrix MO Relation. Also the matrix decomposition is an innovation among the information systems for maintenance, because the usual decomposition is the hierarchy. Obviously, the tree structure is compatible with this, but much more primarily... because it is only one possible configuration among the theoretically infinite combinations that MO Matrix Configuration permits. Figure 3 shows an extract of the Form that permits to manage the Maintenance Plan Module, based on time series forecasting [6].

Nowadays, this module has the possibility to plan the several kinds of planned interventions like the following: Scheduled; Periodic based on a functioning variable; Non-periodic.

Another initial important feature of SMIT was a Fault Diagnosis Module [7] that will be showed later in this paper. Additionally, it was made a new approach with this objective, based on Case Based Reasoning (CBR) methodology, using fuzzy logic, as can be seen in [8], [9] and [10]. Nowadays SMIT continues to be improved through the introduction of new modules, as referred and also with a new orientation in a direction of a more emphasized view of tomorrow, namely an ecologic sustainable future. This is done, by example, through new aspects like the following:

- Maintenance organisation based on a environnemental vision;
- Maintenance planning of diesel engines based on environmental parameters;
- On-condition maintenance of wind farms to maximize the production and minimize the use of fossil resources;
- Optimisation of fault diagnosis to minimize the waste;
- Managing life cycle of Maintenance Objects (MO) in order to optimise its period of functioning and reducing the necessity of production of new MO;
- Fault diagnosis through 3D models.

4 FAULT DIAGNOSIS TROUGH A JOYSTICK

The fault diagnosis that will support the 3D visualization system that is inserted in SMIT obeys to the following structure: Occurrence; Cause; Procedure.

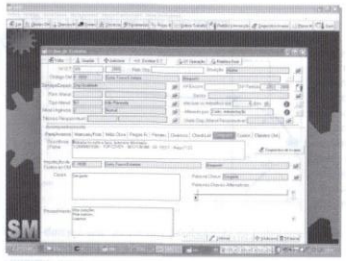

Fig. 4 – Non-planned WO and diagnosis data

Figure 4 illustrates the form corresponding to a non planned Work Order (WO), in which the precedent data diagnosis is inserted. Associate to these data can be added key-words for an easier subsequent research. The data diagnosis is accessed through a specific module, being the information accessed through the forms illustrated in figures 5 and 6 . The first correspond to the occurrence, the second to the cause and the last to the procedure that allows to solve the fault. It is posible to introduce key words for more easily to follow the diagnosis process. The 3D visualization will have to be associated to each diagnosis step and, in particular, to the check list of procedures that will solve the fault.

The missing part of resolution of the fault will have to be made available to the technician in order to prevent situations of missing pieces or forget making regulations. An approach of great potential, both in the planned maintenance and in the fault diagnosis is the use of the Web (Torres Farinha, et al., 2001). Then, by the fact of in some types of facilities and equipments there exist few installed units and by the fact of to be easier and faster to enrich the fault diagnosis library, the evolution of this SMIT module and the module of 3D visualization through a collaborative way will correspond to a great step in front in the maintenance activity. The figure 7 shows a 3D simulation of an industrial facility.

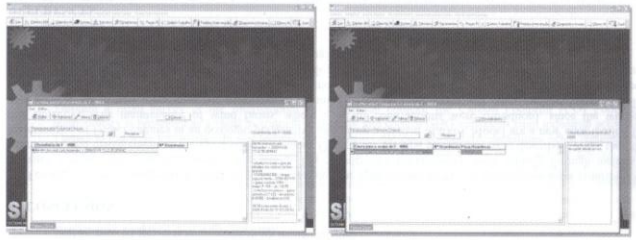

Fig. 5 – Left: Fault diagnosis – Occurrence, right: fault diagnosis - Cause

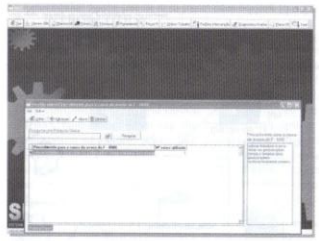

Fig. 6 – Fault diagnosis – Procedure

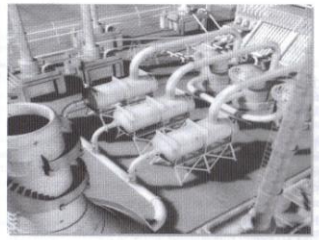

Fig. 7 – 3D industrial facility model

This new approach will permit to travel within the MO through the use of a joystick, like a game, aided by the SMIT fault diagnosis module. This is an innovative way that has much more potential to come, like the following possibilities:

- Training the functioning of the MO;
- Training new maintenance technicians;
- Performing remote maintenance interventions;
- Designing 3D animated solutions to solve fault problems to send to a customer by email in order to minimize the number of visits to the customer;
- Developing interactive 3D models so they can be analised closely.
- E-learning training.

5 DIESEL ENGINES

It seems obvious that in an environmental perspective the best maintenance procedure for Diesel engines was to eliminate them. But, as the "optimum is enemy of good", that objective must be achieved step by step. Most part of economy is supported by the petroleum and it is not possible to change things from one day to another. It is necessary to change quickly but, under this perspective, an important step is to start to see maintenance through nature's eyes. In the case of Diesel engines, it can be used national and international environmental regulations and studies as references [11][12]. Some pollutants and other variables are regulated in it, like the followings: Particles with dimension less than 10 μm (PM10); NO_x; CO; HC; CO_2; fuel consumption; noise level; and some oil variables environmentally related. There is some contribution that everyone can give for a better environment that is to influence political decisions to the governments by ecologic transports and use maintenance management policies like those here explained, among others. The main objective of the research that is carried on is illustrated in figure 8 [13].

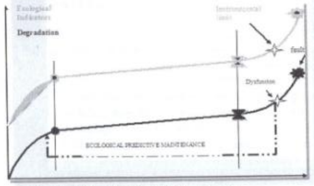

Fig. 8 - To predict the next intervention

The methodology here explained is under development and the model is being validated in a public fleet bus in the city of Coimbra, in Portugal. The maintenance management methodology is an on-condition model based on a prediction model that uses a Hidden Markov Model (HMM). A Hidden Markov Model is a statistical model in which the system being modeled is assumed to be a Markov process with unknown parameters. The challenge is to determine the hidden indicators from the observable variables. In this case, the data corresponds to the consecutive registrations of effluents from Diesel engines [14]. The measurements are made through data collected in the Diesel engine exhaust system and also through control system that includes, among others, air mass meter, air temperature sensor, air pressure sensor, water temperature sensor, crankshaft position sensor and camshaft sensor. The data collected is used for training each HMM. The time series of collected data correspond to inputs to an HMM for variable evolution prediction. The model is being validated and the results seem promising. After all it is believable that the public transport company that is supporting the present research will accept to change its maintenance management for a better and environmentally sustainable model that is being developed [15].

6 WIND GENERATORS

A wind turbine is a complex system with several components which constantly move and support strong forces. By consequence, it can have problems, such as vibrations, electrical failures and many other kinds of faults. Additionally, wind farms are usually far from cities and from companies that support their maintenance. Technical assistance is expensive and the combination of on-condition maintenance with the best practices of operational research to minimize distance costs is extremely important. Within this work, the main objective is to implement a maintenance plan using, namely, on-condition maintenance through on-line data instrumentation, acoustic techniques, vibration techniques [16], infrared images, stress measurement, zero crossing current analysis and artificial intelligence, in a coherente and synergetic way. Figure 9 shows a graph with a vibration spectrum using Fast Fourier Transform (FFT) from a motor data [17].

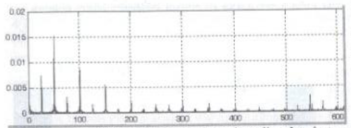

Fig. 9 – Vibration analysis using an FFT with 6000 points, fs=2kHz

SMIT is able to acquire wind speed, axis rotation, active and reactive power and vibration signals. The techniques used to monitor the condition of the wind system are based on the following aspects:

- Vibration monitoring on generator and gearbox;
- Measure the wind speed, using an analogue anemometer and a ultrasonic anemometer;
- Active power measurement;
- Classification using artificial intelligence;
- Time series analysis using regression techniques;
- Weather monitoring station.

The complete model is, at the present time, to be completely validated and the results are concrete and, by consequence, it could be implemented in a near future in thousands of wind generators.

7 INTEGRATED SYSTEM

The main objectives of all developments that are being done by the team are around terology and taking as purpose an environmental sustainable earth. All developments are supported by SMIT and enrich it. But, at present time, the new hardware and software solutions require a more complex integration and communication among the several pieces of this complex "puzzle". Figure 10 shows a real configuration to integrate the several terology pieces. Simplicity was always a concern, friendliness, and low cost of all system, as can be observed in those figures. The central system is based on a Linux Server running apache web server and PostgreSQL database [18]. All systems are available through IPv4 connectivity from the acquisition system level to the Linux Server and SMIT clients. Data acquisition can be done using special low cost hardware, as also by high performance acquisition systems like National acquisition hardware using LabView (connections to SMIT server is also obtainable by IPv4 connectivity), and Ethernet PLC's. It is also available on the SMIT Server, a Fax server (Hylafax), and a TCP/IP server for reception of data acquired from different acquisition hardware, using UDP packets with acknowledgement.

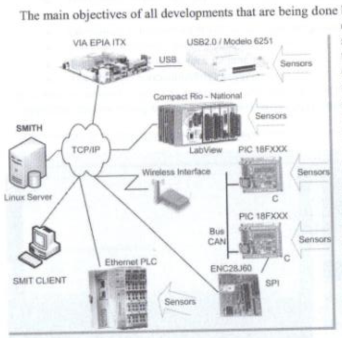

Fig. 10 - An integrated system for terology with on-line data reading

Nowadays, SMIT has or is to have, new adding like the followings:

- Wireless communication to IP devices to receive measurements from any MO, like Wind Generators, Diesel engines, or any others;
- On-condition modules to predict planned interventions based on variables that are regularly measured being by remote way, by physical connecting or by human reading.

8 CONCLUSION

Terology is a more wide way to understand maintenance. The approach made by this team shows some contributions to reach a more environmentally sustainable world. The maintenance management itself, namely through materials, conditions, and management of life cycle of Maintenance Objects are the first things that were described. After that, the maintenance of Diesel engines in an ecologic perspective and using a Hidden Markov Model are a new contribution for that objective. The maintenance of wind farms, where a lot of contributions were introduced, since the wireless communications to new algorithms for maintenance planning based on time series and other methodologies are also referred. A new approach of fault diagnosis aided by 3D models is a very new value added, also presented in the paper. Finally, the integration of all these components shows terology has a large spectrum and is increasing its inclusion of new contributions to be possible to have a sustainable and ecologic world for a better future.

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NEW APPROACH OF MAINTENANCE IN A "GREEN COMPANY" BY ANALYZING "CARBON FOOTPRINT"

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SUMMARY

Through a rapid survey of the international environmental context, the Carbon Footprint (CO_2 Footprint) methodology is presented as a valid instrument to monitor and control GHG emissions from industrial activities. Thanks to the wide knowledge on site technological systems and data collection capabilities, often regulated by contract, maintenance companies can actively support their clients to fulfill their environmental policies. The joint use of the Carbon Footprint methodology and an Energy Audit analysis scheme can answer the Client's demand of environmental linked efficiency assessment, and lead to a wide range of initiative that can extend the maintenance service perimeter. An experience of Carbon Footprint assessment approach on industrial site is presented in order to give the reader an example of the possibilities that can derive from a structured use of data, maintenance workmen deal with every day.

Key Words: Climate Change, CO_2, Carbon Footprint, Energy audit, GHG Emissions

1 INTRODUCTION

The greenhouse effect is a natural phenomenon. Certain gases such as carbon dioxide (CO_2) and methane (CH_4) – already present in the atmosphere in small quantities – trap a large amount of solar radiation. Their role is to maintain an average temperature on Earth of about 15 °C. Without Green House effect the average Earth temperature could reach the freezing temperature of -18 °C, with imaginable consequences. Economic development – principally based on natural energy derived from combustion of oil and carbon – has determined a rise in concentration of these gases, called rightly Green House Gases (GHG). Human activities sap the fragile Earth system equilibrium in a dual way if thinking about the contextual over-exploitation of natural areas, like deforestation, that weakens gas absorption capabilities (in particular CO_2, essential for photosynthetic processes). Overall effect is an alteration of Earth's energetic equilibrium that is now showing itself in the fast rising of Earth's surface temperature. It has been foreseen that, until 2100, Earth's average temperature will rise between 1.4 and 5.8 °C. Many studies linked atmospheric mean temperature rise with climate change (droughts, storms, etc.) and derived effects like desertification, sea level increase, coastal floods.

The awareness of a problem of this size, has determined, not easily, global actions to reduce CO_2 production (and the other, more dangerous, GHG). International agreements, like Kyoto protocol, allowed to define sustainability objectives to reach with policies focused on development and spread of low consumption / high efficiency technologies, incentives on renewable energy production, protection of natural CO_2 reservoirs (like forests), etc. Locally, sustainability goals achievement, is helped more and more with application of "green taxes" and excises, in accordance with the principle "who pollutes more has to pay more". From all these remarks is therefore born the need to evaluate one's own environmental impacts, using a comparable unit of measurement and a standard methodology.

Own GHG emissions assessment is not only a direct response to law requirements but it's a way to achieve several benefits. First of all money savings: emission assessment analyzes direct and indirect emission sources, focusing on sectors in which consumptions reduction can provide either cost reduction and environmental impact minimization. Same importance has the image improvement which, in a context every day more aware of environmental problems, can provide a commercial advantage over own competitors. Finally, constant monitoring and continuous improvement of own consumptions/emissions reduction performance, guarantees an advance response in law contexts more and more demanding.

2 CARBON FOOTPRINT ASSESSMENT METHODOLOGY

Carbon Footprint is an indicator that answers the requirements described above, capable to assess human activities impacts over the environment, in terms of GHG production, measured in equivalent carbon dioxide tons ($teCO_2$). Company or service Carbon Footprint Assessment (CFA) main objective is to estimate emissions from own processes, either direct and indirect, for