Recyclability in Wind Power Area and the Consequent Economic and Environmental Impact

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Abstract

Wind power plays an important role as sustainable energy source, but some technical issues of wind power area can be a severe drawback on the development of wind farms in the short term. One important question is repairing of wind turbines, huge and high technological equipment which recycling poses crucial environmental and economic problems. Thus, this work aims for a better understanding of material balance and specification regarding recyclability and usability of wind turbines that suffer corrective maintenance. The applied methodology was the case study. The case study site chosen has a specific area only to deal with repairing and recycling. Process audit shows several steps that, if correctly managed, could save for recycling a large amount of metallic material. Considering the high cost of the discharged material, this can be an excellent opportunity for medium and small enterprises.

Keywords: *wind power, waste minimization, flow analysis, industrial symbiosis*

1. Introduction

On the pursuit of more sustainable energy sources, wind power appears as one of the most important solutions. Furthermore, in Brazil, the feasibility of large wind power production is unquestionable; for instance, in a rough estimative and considering only speed values larger than 6 m/s, wind potential is approximately 143 GW (ATLAS), i.e., roughly 50% of the hydroelectric potential, 260 GW (Moretto, 2012). However, nowadays, only 3 % of this amount has been actually produced; thus, this panorama points out to high growth rates on wind farms installation in a short period of time. On the other hand, the particularities of wind power area can be a major issue on the development of wind farms in the short term. Due to the high economic constraints of this area, which requires large amount of initial investment and life cycle period of 25 years in order to obtain adequate return on investment (ROI), and the consequent environmental impact if lifecycle is shortened, most research on this area is quickly applied, i.e. without proper field tests since time is a huge limiting factor. Nemet (2008) already described this dilemma for wind power on California and characterized it as a balance between pull demand and push technology policies. The author points out that in three decades the high increment on wind power in California was owing to an approach of "by-doing/and-using", i.e., an incremental improvement even in a recent installed facility; in other words, changes are made a year or two after the wind farm installation that usually requires a year to be completed (Crawford, 2009). However, as in any other competitive business, innovation also plays an important role and is responsible for delay the ROI even more. Moreover, Taylor (2008) states that environmental innovation policy is the main driving force for innovation to occur; therefore equipment development and installation is an important research subject on wind power area.

Nonetheless, on the whole lifecycle of wind turbines, not only production and installation present issues that demand thoroughly research but also the functioning period as well. During the 25 years long operation, it is expected that small or non-maintenance be required since the turbine works in a 24/7 service; however, wind turbines are usually installed in hazardous environments, such as close to the coast where the large concentration of salts present in the atmosphere might corrode the entire equipment (Horgan, 2013). This condition implies that the lack of predictive maintenance should be compensated by online surveillance, for instance with remote sensors; notwithstanding the approach is normally much more conservative. Ng (2013) considers that virtually no attempt is currently been made for a proactive action on faults prevention, such as a better knowledge of physical, chemical, mechanical properties of materials used on turbine production. A singular example is NdFeB magnets, essential on wind turbines but easily corroded by water exposure; this condition normally ask for surface coating approach but, although such coatings are researched since 1990´s (Man, 1996), up to now the commonest procedure is subject the magnet to several thick layers of polymeric material, a much less efficient way for surface protection (Liskiewicz, 2014).

As a consequence of rapid changes (push technologies) that give rise to incremental modifications on installed equipment that must fulfill an urgent task (demand pull) an endless circle of needs/issues is established, and, as a final result, severe failures in installed turbines became more and more common (Crawford, 2009). This failures impact economically the entrepreneurs especially due to insurance demands, as pointed out by Foyer (2014). According to this author's research, severity of claims is far more important than frequency, because even a simple occurrence, such as lighting, means $500,000 debt just to change the blades, not to mention lost of income due to the lack of activity. Xin (2014), auditing China power farms, also concluded that wind turbine accidents are becoming a global concern, with wind turbine burn and collapse as the primary worry.

Wind power turbines are huge and high technological equipment that after lifecycle ending should be recycled mandatorily, for economic and environmental reasons. According to Yang (2012) wind power equipment is mainly composed by "the rotor, pitch system, cabin, gearbox, yaw system, braking system, generator, electrical inverter system, main control system, sensors, hydraulic system, tower and foundation"; among them the most troublesome components are the gearbox and the yaw system, which means disposal of high cost material and equipment; nonetheless, such parts are mostly formed by metals, which favor recycling. Cherrington (2012) considers that, although blades and foundations are the main responsible for waste production, recyclability is high; for wind turbines, excluding the foundations, recyclability is approximately 80% by weight. The author lists the main materials present on wind turbines as steel, aluminum, copper, glass fiber, polyester, carbon fiber and epoxy and claims that metals are highly recyclable and show economic value whereas glass and carbon fiber, present on turbine blades as composite materials (mixing of fibers, matrix and fillers) that degrade due to the hostile environmental conditions during use, can be a hindrance for all the process. Thus, the main problems to be considered during recycling of wind turbines blades are: 1) logistic for dismantling, transportation and cutting, due to the large size; 2) better technological solution for composites recycling and 3) market for the recycles and economies of scale. A possible solution proposed by this author is similar to an industrial symbiosis, with industries setting up collective programs with a closed-loop recycling occurring inside this specific area, i.e., fibers being processed back into the blade. Cherrington (2012) suggests as benchmarking the automotive and aerospace industries that faces similar issues of waste disposal.

The advantages of wind power technology as a greener solution for energy generation is undeniable. Nemet (2008) describes it as a non-greenhouse emission energy source, commercial available at reduced costs; Kaldellis (2011) cites wind power generation as environmentally correct, the major environmental impact occurring during air turbine production and Dones (2007) points out that most of the consumed material can be recycled after its life cycle. Nevertheless, low efforts were done for better understanding recyclability of wind turbine during maintenance cycles, i.e., before decommissioning. Therefore, this work aims for a better understanding of material balance and specification regarding recyclability and usability of wind turbines that suffer corrective maintenance.

2. Methodology

This works was performed in a particular site of wind turbines repair, in order to obtain the main data regarding waste formation and mass balance in wind power area. This site has the main features as follows: The site every week has as mission of approximately manufacturing 5 wind turbines and repairing 1 wind turbine. This Company is composed approximately for 500 employees, 70% of these groups belong to technical personnel, mainly engineers and technologists. They are divided in 7 main departments, between then: Manufacturing, Engineering, Quality, Maintenance, Human Resources, Logistics and Finance and Administration. Regarding manufacturing and repairs, the main involved processes and respective main function are:

a. Material picking and distribution, mainly involved in manufacturing;
b. Assembling process, mainly involved in manufacturing;
c. Technical inspections, mainly involved in manufacturing;
d. Commissioning tests, mainly involved in manufacturing;
e. Disassembling process, mainly involved in repairing;
f. Move logistics, mainly involved in repairing;
g. Performance and technical evaluation, mainly involved in repairing.
h. Repairs – specific area and process to evaluate all the cycle of repairing wind turbines;

Therefore, this site can be considered as a major player in this area and, most probably, its data allows inferring the possibility industrial symbiosis meaningfully. Furthermore, the methodology follows the recommendations for case studies that states that case study fulfills 4 different steps (Yin):

1. Set up - this phase generates the planning of execution, starting with all technical data to evaluate the case as a whole;
2. Selection of the case and survey - from the moment that it is clear the study object, is select the case and information that present major relevance according to objective of the study;
3. Development (driving) process - it is established the research focus. Therefore, it is raised the variables and adequate instruments to apply in the evaluation. In this case study, the methodological tool was observation and technical analysis;
4. Enclosing - after all information is collected, the flow analysis answers the fundamental question: if it is possible to establish industrial symbiosis

Data mining and analysis used the ERP (Enterprise resource planning, in this case SAP 6.3) software installed in the site and considered the steps formerly proposed by Queiroz (2007). In summary, a material flow analysis is accomplished and, as a consequence, main indicators are defined, searched and then exposed in a way that reveals possible connections with partnerships, i.e., indicate possible unrevealed industrial symbiosis. It is worth noting SAP is usually found in 70% of the electronic sector (Queiroz, 2007), which facilitates data exchange in case industrial symbiosis is found.

Flow material analysis as provided by ERP software is, in a way, quite similar to the mass balance usually carried out in chemical industries; nonetheless, flow analysis is much more advantageous if discrete material is handling because, in this case, provides a better understanding of traceability and quality issues.

3. Results and Discussion

This item briefly describes the case study site. After that, process steps needed by wind turbine recycling and repairing are followed. After the definition of critical steps and indicators for flow material analysis, ERP is used to carry out data acquisition. With the gathered information, critical analysis is performed and shows the possible more environmental correct actions, such as industrial symbiosis.

3.1. Site description

The manner in which the extracted energy is converted into usage energy depends upon particular turbine design. The wind turbines produced and repaired in this site follow the schematics showed in Figure 1a. In this case, it is employed a rotor of 3 blades rotating with an angular speedy about an axis normal to the rotor and parallel to the wind direction. Therefore, the wind turbine pieces and parts are rotor blade, cast hub, pitch drives, generator rotor and stator, base frame and tower (not considered in this study or produced in the site). As explained latter, the most probable place for fault generation, is in the stator, an integrating part of the generator; therefore, generator assembling and disassembling process is a critical step on this site. The generator assembled in the site is a synchronous machine with variable speed, permanent magnet excitation, external rotor 88 poles in the stator coils, outer diameter generator < 5.0 m, length of the external generator < 1.5 m. Figure 1b shows the schematics of the generator assembled with bearings as detail. Figure 2 shows parts and pieces, rotor and stator, actually being assembling in the site. As can be noticed in the figures, the scale of each piece poses an enormous difficult in moving them and also corresponds to an especial problem for safety procedure. Moreover, these two pieces, after assembling, must be coupled inside an even bigger structure, called nacelle. The nacelle transmits all static and dynamic loads from the rotor and generator to the tower and allocates all the control panels, the yaw control and monitoring systems (anemometer and weather vane) and transfers the movement around the rotor and allocates the entire pitch control system. Figure 3 shows the nacelle lifted in the air previously the assembly.

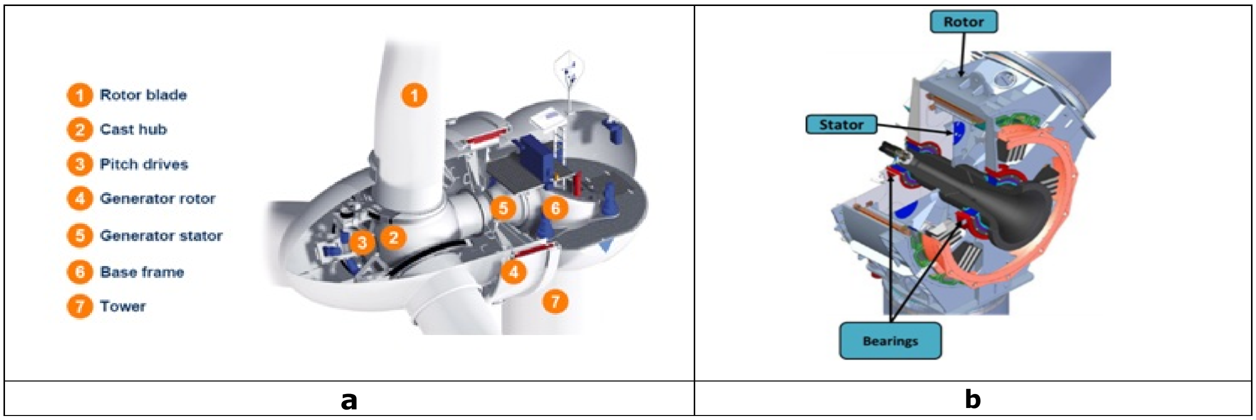


Fig. 1. Schematics (a) Wind turbine and its components; (b) Assembled generator with rotor and stator

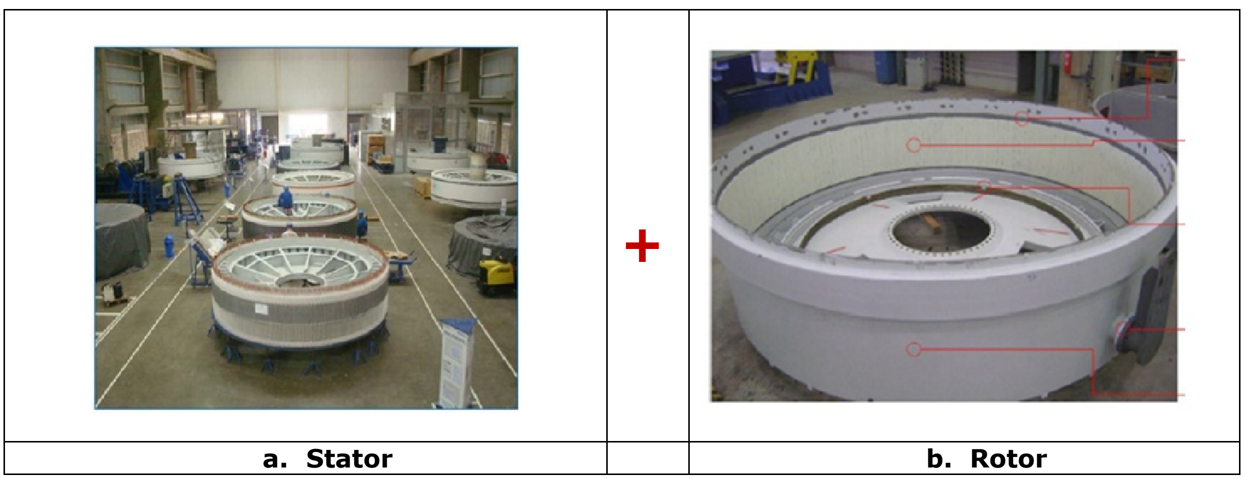


Fig. 2. The generator parts, stator and rotor

Fig. 3. Nacelle

3.2. Process description

The process cycle, for assembling and/or disassembling, was audit regarding material flows and the indicators used in Pareto´s principle acted as a guide on definition of critical points for evaluating industrial symbiosis. Any step that deals with a large amount of material was considered critical if that step also pertained to the recycling area where faults usually occur. Figure 4 presents a generic process flow (some information is removed due to confidentiality reasons) and also highlighted the critical steps. It worth noting that assembling and disassembling cycles are the same, i.e., they just occur in reverse order. The main reasons why each step showed in Figure 4 is categorized as critical, according to Pareto´s principle, is as follows:

- Step #1. It is comprised by more than 20000 pieces of iron that weight approximately 3 tons. Due to the high aspect ratio (thin laminated with large length) that must be completely flat, which is difficult to accomplish during disassembling, i.e., is quite common to be destined as scrap.
- Step #2. Mainly high quality copper material, i.e., an expensive raw-material. Moreover, reuse requires the preservation of a 3D exquisite structure, i.e., a not easy quest.
- Step #3. Expensive organic polymeric material. Due to production process features (vacuum impregnation), there is no easy way to separate the resin from other parts, which implies that recycling is improbable, and a high amount of scrapped mixed material are formed.
- Step #4. Magnet highly expensive material. Up to know economically feasible recycling process that preserves magnet properties is unknown, which means that the material will be sold as scrap.
- Step #5. Similar to step 1
- Step #6. If the procedures are correctly done, all the rotor structure will be preserved, which means more than 10 ton of metallic material being recovered.
- Steps #7; #8 and #9. Similar to step 6

In conclusion, this previous analysis shows that, if all the procedures are thoroughly accomplished, a large amount of metallic and expensive material will be recovered. However, statistically the main failures, usually short circuit, have been occurred in this critical area (LIMAD, 2014). It is well know that short circuit, especially severe ones, can damage the material properties of these samples, which will decrease the possibility of resale value. Figure 5 shows schematics of the critical region due to possible short circuit and the corresponding affected components.

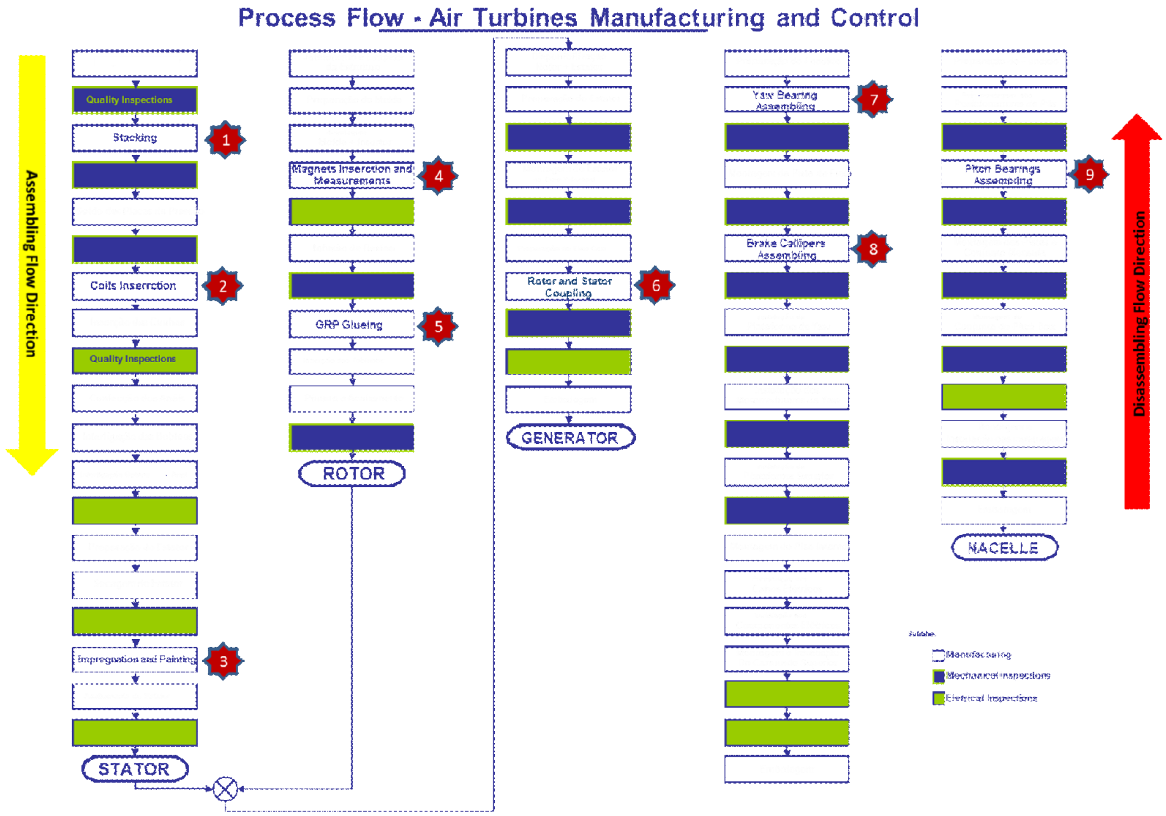


Fig.4. Process flow of assembling and disassembling (only critical steps are highlighted, due to confidentiality issues)

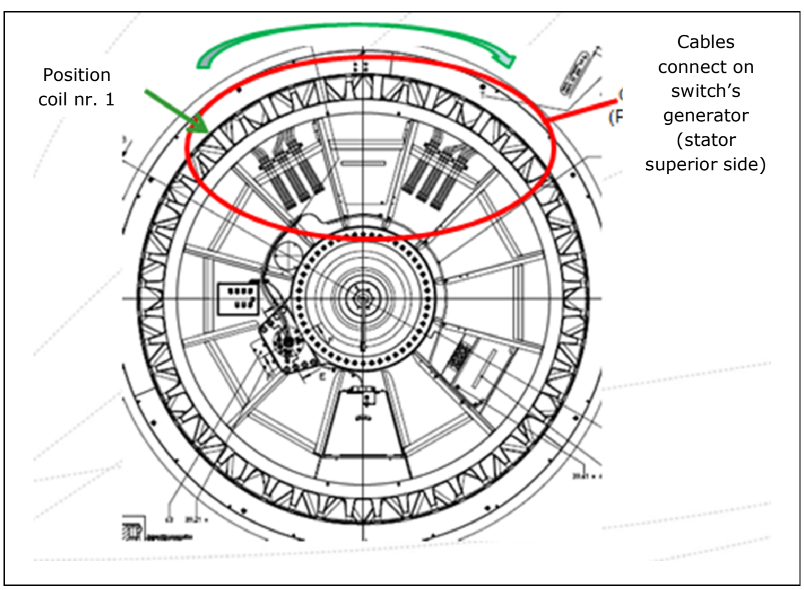


Fig. 5. Schematics of critical region for short circuit and affected stator components

3.3. Flow analysis

As pointed out by Graedel and Allenby (2002), the production of closed production cycles requires the fulfillment of technical, economical, organizational and legal steps. In this study, there is no legal impediment for this recycling or, conversely, none incentive for this task. Technically, it will be difficulty, due to the complexity of the process, but not be impossible to be done. Thus, economical and environmental issues will be the major concerns.

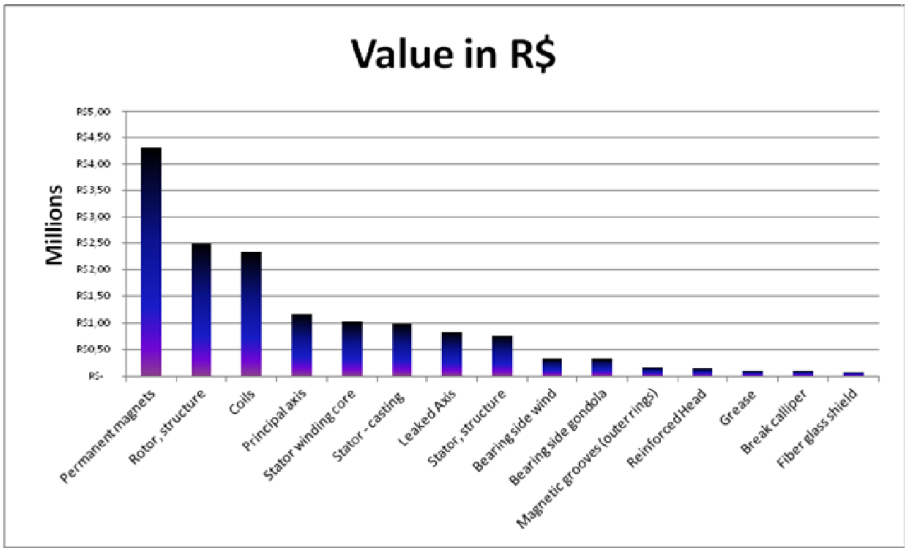
ERP is a powerful tool for material analysis (Queiroz, 2007), therefore, the formation of critical material, as defined by process flow analysis, was followed during 6 continuous months on the site. The main results were splitter regarding human resources, material analysis. On this site, impact on costs is primarily due to materials (the highly expensive components), infrastructure, and due to expensive devices that requires constant maintenance, and human resources that corresponds to a highly specialized but small team.

The disassembling and possible remanufacturing requires approximately 20 days on the site for each set, which means almost the same time for assembling and recycling process. The immediate consequence is a high cost of human resource, or, in other words, any attempt to recycling must be carefully evaluated in order to provide the maximum recover or it will not compensate the investment. Thus, the approach used is a compromise among time expended on the whole process and the disassembling actions; if the actions are time consuming beyond a previous defined target, pieces are discharged without further treatment, which increases the impacts on the environment. A possible solution is to establish partnership (industrial symbiosis) to recover such material; this attitude, however, requires training of non-specialized persons, and the logistic, due to the dimensions involved, must be carefully understood.

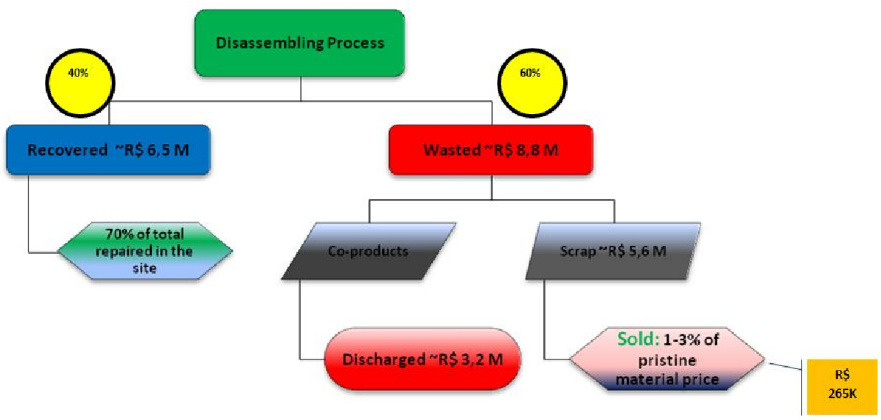
The table 1 shows the main information used to propose industrial symbiosis whereas figures 6 and 7 show the conceptual map of gain and losses account obtained after flow analysis for economic (income) and environmental (mass) aspects, respectively. It is possible to observe a large amount of discharged material that could lead to industrial symbiosis. Considering the high cost of the discharged material, this can be an excellent opportunity for medium and small enterprises.

Table 1 – Inventory of wind turbine components repaired in R$ and weight

Top 10	Description of Materials	Value in R$	Weight in tons
1	Permanent magnets	4308864,00	13
2	Rotor, structure	2482686,00	11
3	Coils	2324851,20	5
4	Principal axis	1155937,64	6
5	Stator winding core	1028048,00	22
6	Stator - casting	985724,32	17
7	Leaked Axis	827960,10	1,2
8	Stator, structure	764000,16	42
9	Bearing side wind	322998,72	1
10	Bearing side gondola	320023,22	0,8
11	Magnetic grooves (outer rings)	165957,12	0,8
12	Reinforced Head	131469,36	0,8
13	Grease	100851,52	0,6
14	Break calliper	85462,74	0,2
15	Fiber glass shield	78852,40	0,1
	Total	**15083686,50**	**121,5**

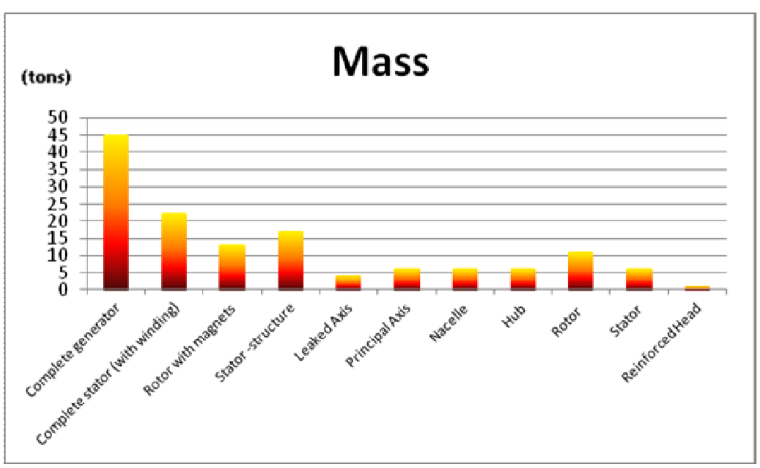


(a)

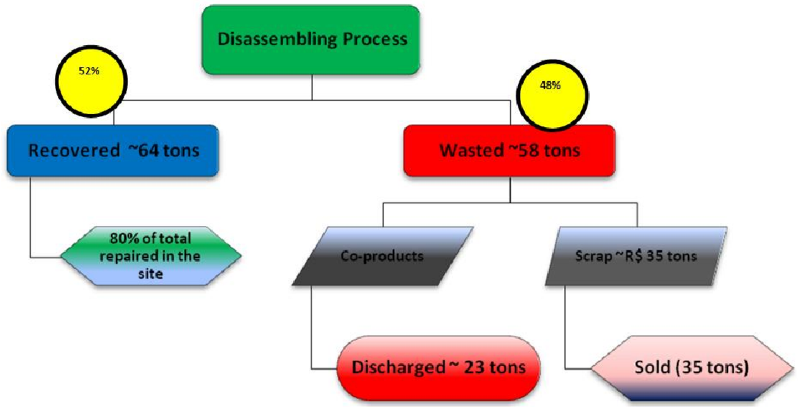


(b)

Fig. 6. Conceptual map: flow analysis for economic (income) aspects: (a) Pareto's Diagram (b) Schematics for industrial symbiosis



(a)



(b)

Fig. 7. Conceptual map: flow analysis for environmental (mass) aspects: (a) Pareto's Diagram (b) Schematics for industrial symbiosis

4. Conclusions

This work aims to a better understanding of mass balance on recycling of wind turbines. It was possible to observe several critical processes during the recycling process that could lead to discharge of a high amount of useful material. The main reason for that action is the time consuming tasks involved, which could be carried out by small or medium enterprises if industrial symbiosis was pursuit.

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