PROJECT ACRONYM: SyrNemo

PROJECT FULL TITLE: "SYNCHRONOUS RELUCTANCE NEXT GENERATION EFFICIENT MOTORS FOR ELECTRIC VEHICLES"

GRANT AGREEMENT NO: 605075

Deliverable number: D1.8

Report on Quick Eco scan

Document No:	SyrNemo-D1.8 report
Issue. Revision:	1.0
Date:	25.04.2014
Prepared by:	Responsible lead partner (Maria Hernandez, Maarten Messagie, VUB)
Contributions by:	Antonio Fricasse CRF, Erwin Schlemmer AVL
Approved by:	Full Name, Partner Abbreviation

Dissemination level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission	
RE	Restricted to a group defined by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

TABLE OF CONTENTS

1 SUMMARY

The present deliverable collects useful information for the design of the electric machine (Synchronous reluctance motor SyRM), of the SyrNemo project, from an environmental point of view. The electric machine under investigation is intended for traction of passenger vehicles.

The ecoscan covers a hot spot assessment, through a Life Cycle Assessment (LCA), for the identification of Key Environmental Performance Indicators (KEPIs). The environmental impact of each of the stages in the life cycle of the electric motor is highlighted. In addition, a comparison is performed, between several material alternatives, establishing which material option has the potential to decrease the overall environmental impact of the motor.
The ecoscan also covers general Ecodesign recommendations for selection of "ecomaterials", management of the supply chain, and manufacturing and assembly to enhance recycling. Finally, an overview of environmental European legislation, concerning electric motors, is presented.

2 DESCRIPTION OF DELIVERABLE

Deliverable 1.8 contains the main environmental concerns associated to synchronous reluctance motors. A life cycle thinking approach is used in the deliverable, to identify key environmental impacts generated, and the component, material or process responsible for this impact.

The ecoscan covered in this deliverable contains: first, an assessment carried out to discover main key environmental performance indicators (KEPIs). Then, a comparison, for alternative materials in the motors components, with an emphasis in the key indicators previously identified. In this way, the materials producing smaller environmental impact are spotted.
Following the ecoscan, a set of Ecodesign suggestions is presented, indicating general strategies to reduce potential environmental impact while selecting materials and suppliers, and manufacturing techniques to facilitate end-of-life recycling. Lastly, a revision of environmental legislation at European level is presented to be taken into account during the design process.

2.1 Contribution of partners

AVL has provided a Bill of Materials of a permanent magnet synchronous motor. From here, typical materials and components of synchronous motors are established.
CRF has contributed with the Bill of Materials used in the design of the HySYS machine. This BoM is used as a reference for components and quantity of materials constituting a SYRM.

2.2 Deliverable outcome

The outcome of this deliverable can serve to guide the design process of SyrNemo, in order to achieve the lowest possible environmental impact, by taking actions from the very beginning of the project.

2.3 Abbreviations

LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
ILCD	International Reference Life Cycle Data System
KEPI	Key Environmental Performance Indicator
SYRM	Synchronous Reluctance Machine
PMSM	Permanent Magnet Synchronous Machine
ISO	International Standardization Organization
E-motor	Electric Motor
EPA	Environmental Protection Agency
FU	Functional Unit
EoL	End Of Life
MSWI	Municipal Solid Waste Incineration
GHG	Green House Gases

LEED	Leadership in Energy & Environmental Design
EMAS	Eco-Management and Audit Scheme
CDP	Carbon Disclosure Project
DJSI	Dow Jones Sustainability Index
WEEE	Waste Electrical & Electronic Equipment
ROHS	Restriction of Hazardous Substances in Electrical and Electronic Equipment
EUP	Eco-Design of Energy-using Products

3 TARGETS

The main target of this document is to provide guidance for the design of SyrNemo project, and particularly for Workpackage 3 Next Generation Motor Design. Ecodesing throughout the entire project duration is among SyrNemo's project main objectives. This document can be considered as a first tool to support the Ecodesign process, and to ensure minimum environmental impact of the electric machine, right from the beginning to the end of the project.

Four specific targets are set up for this deliverable, and they are described as follows:

1- Identify critical life cycle stages, materials and processes, or Key environmental performance indicators, impacting the environmental performance of synchronous reluctance motors.

2 - Highlight the main impact categories, such as climate change, freshwater toxicity or ozone depletion, resulted from the construction, use and disposal of the SYRM.

3- Evaluate the environmental performance, of different material alternative that can be used in the machine, and suggest which option is more adequate from environmental point of view.

4- Recommend general Ecodesign strategies for selection of materials and suppliers, manufacturing and assembly for recycling.

This ecoscan is intended as a first step in the iterative process of Ecodesign and the full Life Cycle Assessment of the SyrNemo project.

NOTE: All requirements and specifications established in Work package 2, together with this document, will serve in the design process and the realization of tasks covered by Workpackages 3 & 4. This document is in no way intended to be the only criteria for selection of materials and components design, whereas guidance for an environmental friendly design process.

4 IMPLEMENTATION OF WORK – RESULTS

A summarized description of the work performed, and the results obtained for Deliverable 1.8, is presented in three main sections:

- Ecoscan of synchronous reluctance motors and alternative materials
- General Ecodesign recommendations
- Environmental European Legislation concerning electric motors

The content of each section is described in details bellow.

4.1 Ecoscan of synchronous reluctance motors and alternative materials

Section 4.1 refers to the ecoscan, for the identification of KEPIs, using the Life Cycle Assessment of a synchronous reluctance motor, and the study of the environmental performance of different material alternatives that can be employed in the electric motor.

4.1.1 Key Environmental Performance Indicators

KEPIs represent quantifiable metrics that reflect a projects environmental performance on key issues. These metrics are specific for each project, system or organization. In other words, KEPIs are a tool for measurement of the environmental performance criteria. Widely speaking, indicators belong to one of the following categories: emissions to air, water or soil, or resources use. Accordingly, examples for these indicators come in the forms of kg of CO_2 emitted to the atmosphere, kg of oil eq consumed, m^2 of land occupied, etc.

In general, environmental indicators have the following purposes:

- Highlight problem areas and improvement potentials
- Compare the environmental performance over time, and with the performance of other comparable systems
- Facilitate the definition and pursuit of environmental targets
- Control and verify environmental goals and objectives

For SyrNemo, these indicators are recognized by studying the full life cycle of the e-motor (section 4.1.1.1). They will be used to depict the vast quantity of environmental information in a comprehensive, representative and concise manner.

4.1.1.1 Life Cycle Assessment

The Life Cycle Assessment performed for the Ecoscan of the SyrNemo project is conducted according to ISO 14040 [1] and 14044 standards [2], and the International Reference Life Cycle Data System (ILCD handbook) – General guide for life cycle assessment [3]. The mentioned ISO standards divide an LCA study into four steps:

1. Goal and scope definition
2. Life cycle inventory analysis
3. Life cycle impact assessment
4. Life cycle interpretation

The following sections describe the framework and results obtained, for each one of these steps.

1. Goal, Scope and Functional Unit

- **Goal of the study**

The main objective of the assessment performed is to provide support in the design process of the Synchronous Reluctance motor, developed for the SyrNemo project.

The ecoscan assesses the environmental performance of a Synchronous Reluctance Electric Motor (SYRM). The electric motor developed for the HySYS machine (HySYS - Fuel Cell Hybrid Vehicle System Component Development) is used as model, for the estimation of the environmental impact of synchronous reluctance motors. The assessment indicates, in which stage of the life cycle, the biggest share of impact is generated on the environment, and which components or processes are most concerned in this impact. The findings of the assessment are valuable for the identification of opportunities to improve the environmental performance of a Synchronous Reluctance motors, particularly for the selection of the materials for the components of the motor.

The assessment covers the following aspects:

1. Identification of the most critical life cycle stages influencing the overall environmental performance of the traction motor, and its key environmental performance indicators.
2. Comparison of environmental impacts generated by the different material alternatives.

The results of this Ecoscan need to be taken into consideration in the design decision process of the SyrNemo project, together with the specifications and other functional requirements. This study is commissioned by the European Commission in its 7th Framework programme.

- **System boundary**

The Ecoscan includes three stages of the life cycle of the SYRM, these being: material production, manufacturing and assembly, and disposal of the SYRM, as shown in figure 1.

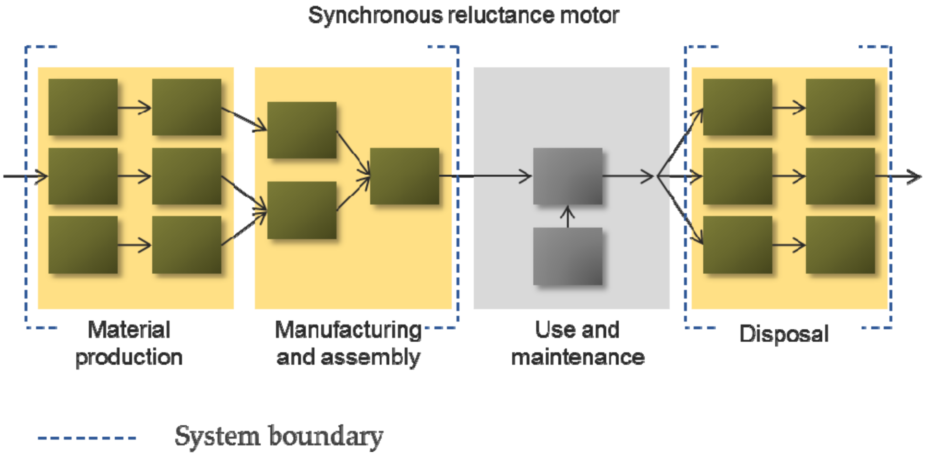

Figure 1. Scope and boundaries of the study

The environmental impact generated by the use stage of the SYRM is calculated separately, and then compared to all the other stages. This approach is taken in order to simplify the calculation process. The use stage accounts exclusively for the electricity used to power a full electric midsize vehicle.

For the comparison of the impacts generated by each material alternative, the analysis will be limited to the specific stages of material production and manufacturing of the motor. The scope of this part of the analysis is limited exclusively to these stages given that the variation between alternative materials has very little or no impact to the use and disposal stages.

- **Functional unit**

The functional unit is a quantified description of the function of a product system. For this study, the product system refers to the Synchronous Reluctance motor. This functional unit used as a reference unit, and it allows the comparison of several product systems.

In this study, the functional unit (F.U.) is defined as the mechanical energy of the motor, expressed in kW. The mechanical power of the SYRM under study is of 45kW. The functional unit of this study is then defined as producing 45 kW of mechanical power. This F.U. will be used in the future comparison of the SYRM with other benchmark traction electric motors.

2. Inventory

The data collection for the life cycle inventory (LCI) concerns two types of data: primary and secondary data. Primary data refers to data provided by the partners of the consortium of SyrNemo and secondary data is the data estimated on the basis of other data sources. This section describes the inventory data collected for each of the life cycle stages. The inventory used for each one of the stages can be found in the appendix section of this document.

- **Material production**

The primary data for the Bill of Materials of the HySYS machine is used for the identification of materials required for the construction of a 45kW synchronous reluctance e-motor, as well as the processes involved in the forming of the components of the motor.

- **Manufacturing and assembly**

Reference [4] is used for the estimation of energy efforts (electricity and heat) required for the manufacturing and assembly of a 45kW generic electric motor.

- **Electricity supply mix**

The electricity consumed, at each one of the life cycle stages, is assumed to be the electricity mix of EU 27 from the year 2011, which the most representative and up-to-date data available to model to consumption. A detailed breakdown by type of energy source constituting the electricity mix of EU 27 (2011) can be found in the appendix. The type of electricity mix used in this study is of particular importance during the usage stage, this given the big amounts of energy expend during this stage, and the nature of the electricity source. This electricity mix has been modelled with data from Eurostat [5].

- **End of life**

The EoL scenario proposed in this study comprises the disposal and recycling of the materials integrated in the motor. From the motor, the aluminium, copper and steel are considered to be recycled, at different recycling rates. The average recycling rates for end-of-life vehicle materials are estimated from [8]. Impregnation resins and insulation materials however, are not considered to be recycled but disposed as waste for Municipal Solid Waste Incineration (MSWI). The inventory for disposal and recycling processes of the materials is obtained from Ecoinvent V2.2 database.

The total burden allocated to waste disposal at MSWI, and recycling of materials, is taken as an additional environmental impact in this study. That is to say that, even though the materials recovered at the EoL stage will go to another product system and they will substitute primary raw materials, the recycling process for these materials will produce emissions to the environmental, and use energy and other resources, which will be accounted for in this study as additional impact created by the e-motor.

3. Lifecycle Impact assessment

In this section the emissions and resources, of the previously defined life cycle inventory, are transformed into easier interpretable impact categories using characterisation factors, as represented in figure 2.

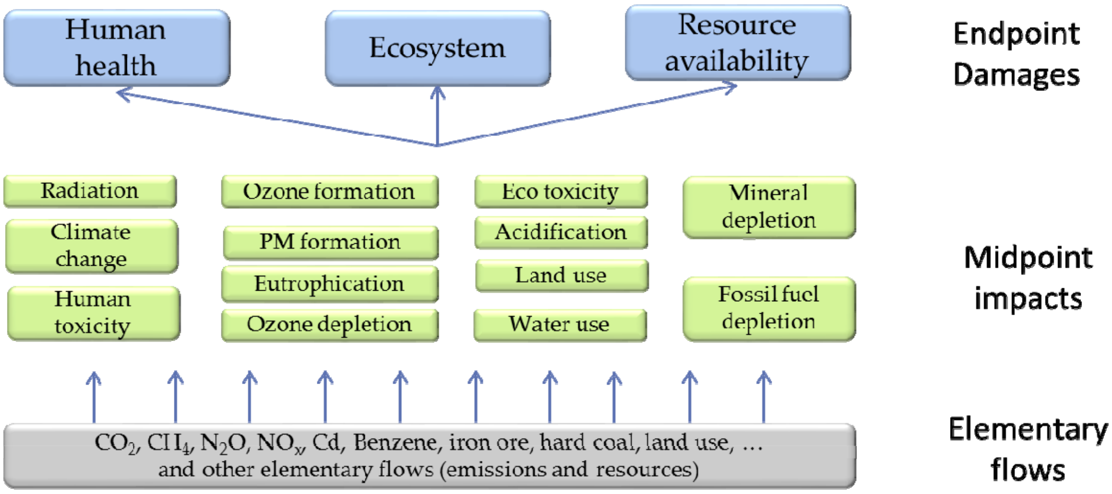

Figure 2. Framework of impact categories for characterization modelling and midpoint and endpoint levels [6].

For this study the applied LCIA method is ReCipe at midpoint level. By focusing at a midpoint level it is possible to analyse in deeper level each one of the impacts generated by the motor, by at the same time avoiding normalization and weighting of the impact, thus reducing the uncertainty of the results.

For the inclusion of impact generated during the use phase of the motor, it is estimated that its lifetime will cover 210.00km of use phase. This value represents the average lifetime of a Belgian vehicle [6]. This value is taken as a representation of the lifetime of the traction vehicle using the SyrNemo e-machine, in Europe. In addition, the average fuel economy of midsize full electric vehicle is equal to 19kWh/100km, according to EPA combined fuel economy [7]. From these two assumptions, the total energy consumed during the use phase is estimated at 39900kWh.

- **Impact categories:**

This section evaluates the contribution of the synchronous reluctance motor to several impact categories. An overview of the respectively contribution of the life cycle stages to each of the impact categories is shown in Figure 3.

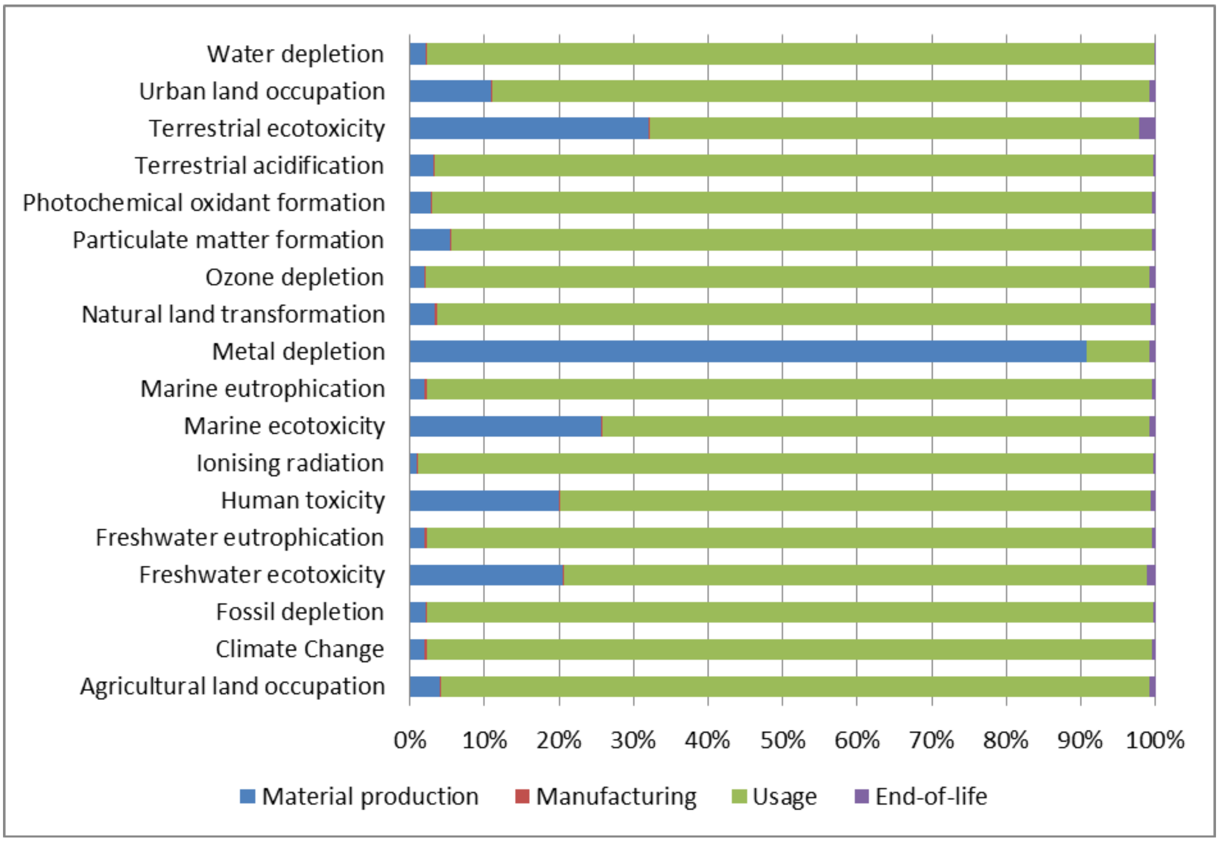

Figure 3. Contribution of the life cycle stages of the SYRM to each impact category.

As this figure shows, the majority of impact categories are mostly affected by the electricity consumed during the usage of the electric motor. Electricity generation, depending on the source, has an intrinsic production of GHG emissions, fossil fuel deletion, particulate matter, and other negative issues for the environment. For this reason, it is critical to pay special attention to the efficiency, and other factors affecting the energy usage of the e-motor, in order to achieve a significant decrease of the overall impact of the electric motor. A detailed electricity mix used to obtain these results can be found in the appendix.

At the same time, manufacturing and end-of-life stages do not seem to have an important contribution to the impact categories. On the other hand, the material production stage contributes considerably to several impact categories, especially to those referring to metal depletion, and human and ecosystems toxicity.

The next section describes then in better details, the materials and processes that originate these impacts during material production stage, expressed in terms of key environmental performance indicators KEPIs. Special attention is given to climate change, given the importance of this issue at global level. Metal depletion and human and ecosystems toxicity are also described in detail as material production has a significant impact in these categories.

Key environmental performance indicators

This section describes the main three environmental issues associated to the e-motor, and the components and materials contributing to these issues.

Environmental issues:

- *Climate change*

The contribution to climate change is estimated from the emissions of kg CO_2 equivalent. As it can be observed in figure 4, during material production, steel and aluminum generate the biggest amount of CO_2 equivalent, accounting for around 70% of the total emissions. The extraction and production of the magnet containing Neodymium oxide also has a considerable part in the GHG emissions. From material production point of view, some improvements can be done by reducing the total amount of material required for the housing of the motor and the magnetic core laminations, and eliminating the use of permanent magnets using neodymium oxide (as it is already one of SyrNemo project objectives).

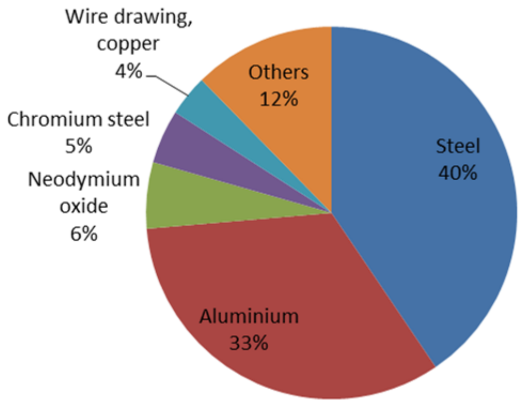

Figure 4. Materials & processes contributing to climate change during material production stage.

Result indicator: emissions to air in kg CO_2 equivalent

- *Metal depletion*

Impact on metal depletion is measured by the exhaustion of Kg of Fe equivalent. The process contributing the most to this category is the extraction and production of steel components of the motor, followed by the extraction of copper. In total they account for about 97% of the depletion of metals. In order to decrease the exhaustion of metals, it is necessary to reduce as much as possible the use of materials for windings, and for the laminations in the magnetic core.

Result indicator: resource depletion in Kg of Fe equivalent.

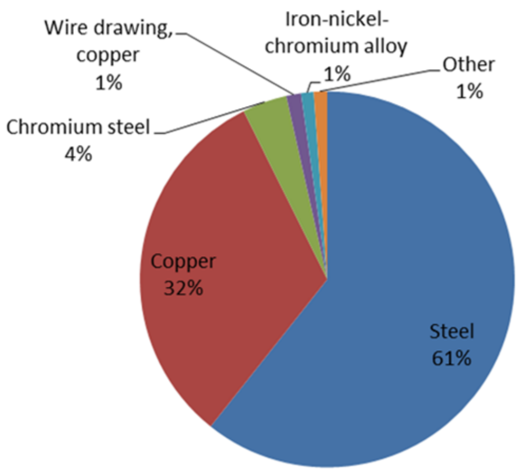

Figure 5. Materials & processes contributing to metals depletion during material production stage.

-

- *Human and ecosystems toxicity*

Toxicity impact to both humans and ecosystem is measured by emissions of kg 1,4-DB equivalent. As it can be observed in Figures 6-9, the major contributor to toxicity for humans and ecosystems comes from the extraction of copper metal during mining activities. Other materials accounting for toxicity impacts are steel, aluminium and to a smaller degree, neodymium oxide. The environmental impact in this category can be significantly decreased by using the optimal amount of copper wingdings as necessary, and paying attention to the supply chain of the copper material to be used, selecting supplier that are the most respectful of the environment as possible.

Result indicator: emissions in kg of 1,4-DB equivalent

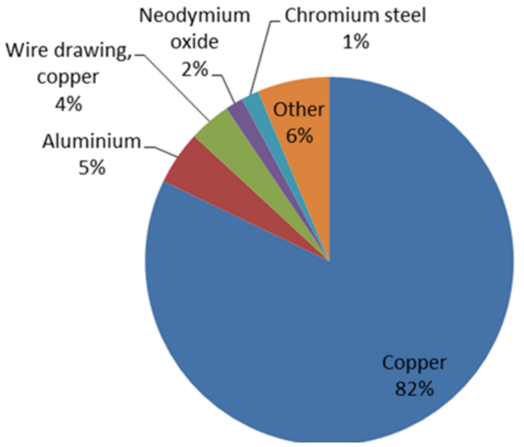

Figure 6. Materials & processes contributing to human toxicity during material production stage.

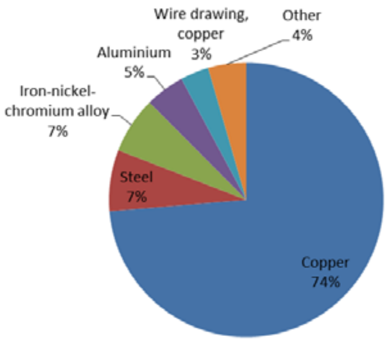

Figure 7. Materials & processes contributing to marine ecotoxicity during material production stage.

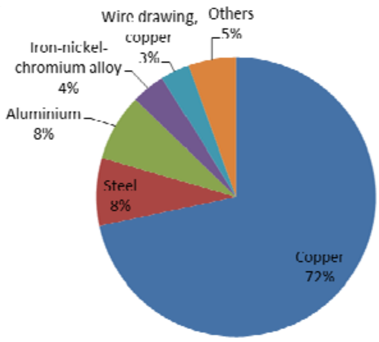

Figure 8. Materials & processes contributing to terrestrial ecotoxicity during material production stage.

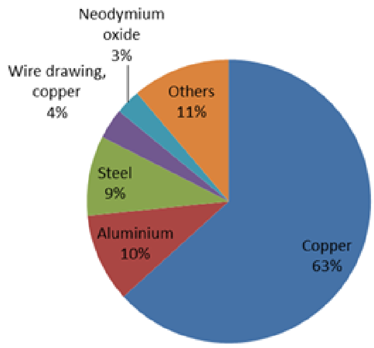

Figure 9. Materials & processes contributing to freshwater ecotoxicity during material production stage.

4. Interpretation and conclusions

From the results of the LCIA it can be concluded that, the energy consumed during the usage stage contributes the most of the life cycle for the majority of the impact categories under study. This can possibly be improved by increasing the efficiency of the motor, decreasing its weight, or improving other factors that decrease the energy expend during usage stage. Results also show that the material production stage has a considerable contribution, particularly comparing to manufacturing and the end-of-life of the motor.

As discussed previously, the overall environmental impact of the SYRM can be improved by reducing to optimal levels, the use of materials for the housing, magnetic laminations, and windings, reducing the use of steel, aluminium and copper. In this way, the total toxicity, metal depletion and climate change impact can be reduced.

Next section studies the influence, on the environmental performance, of alternating materials that accomplish the same function as the ones present in the studied SYRM.

4.1.2 Comparison of environmental impacts generated by the different material alternatives

The objective of this section is to identify the materials that are capable of fulfilling the same function in the motor, and that produce relatively less impact on the environment.

This comparison includes the stages of material production and manufacturing of the motor exclusively. The alternative materials replace its equivalent in the SYRM previously studied. Table 1 shows the materials in the SYRM (Benchmark) that are substituted, and the optional materials for the substitution.

Table 1. Benchmark and alternative materials

Component	Material in SYRM (benchmark)	Alternative materials
Magnet	Neodymium magnet	Ferrite magnet
Resins	Polyester resin	Epoxy resin Silicon Polyurethane
Insulation films	Polyamide films	Cellulose fiber Polyether films Polyester films
Housing	Aluminium	Steel
Wires	Copper	Aluminium

An assessment is conducted evaluating the stage of materials production and manufacturing using LCA principles and framework, accounting only for these two stages previously mentioned. The alternative materials replace the benchmark materials in the SYRM, and the GHG emissions to air, pollutants emissions to water and soil, and other environmental issues, are calculated, for each of the options.

For the presentation of the results, three impact categories has been selected which represent the critical impacts generated by the SYRM during material production and manufacturing, according to the findings from the previous section. These are: climate change, metal depletion and human toxicity. Human toxicity is chosen as representation of other toxicity categories which are also accounted among critical impacts generated by the electric motor.

Results obtained:

The results obtained represent the impact generated by the material production and manufacturing of a 45kW synchronous reluctance motor. These results are presented in two graphs: the graph in the left shows the percentage of the maximum emissions generated by one alternative material, for several impact categories. A one hundred percent value belongs to the material with the highest amount of emissions. The other materials will have then a percentage of that maximum amount. In this way it becomes easier to visualize the material with overall smaller environmental impact by comparison. The figure on the right shows the actual emissions generated by the materials for three key impact categories, climate change in units of kilograms of CO2 eq. emitted, human toxicity in units of kilograms of 1,4 dichlorobenzene (hazardous pesticide) emitted, and metal depletion in units of kilograms of Iron eq. depleted, by the material production and manufacturing of a 45kW SYRM.

Magnet materials

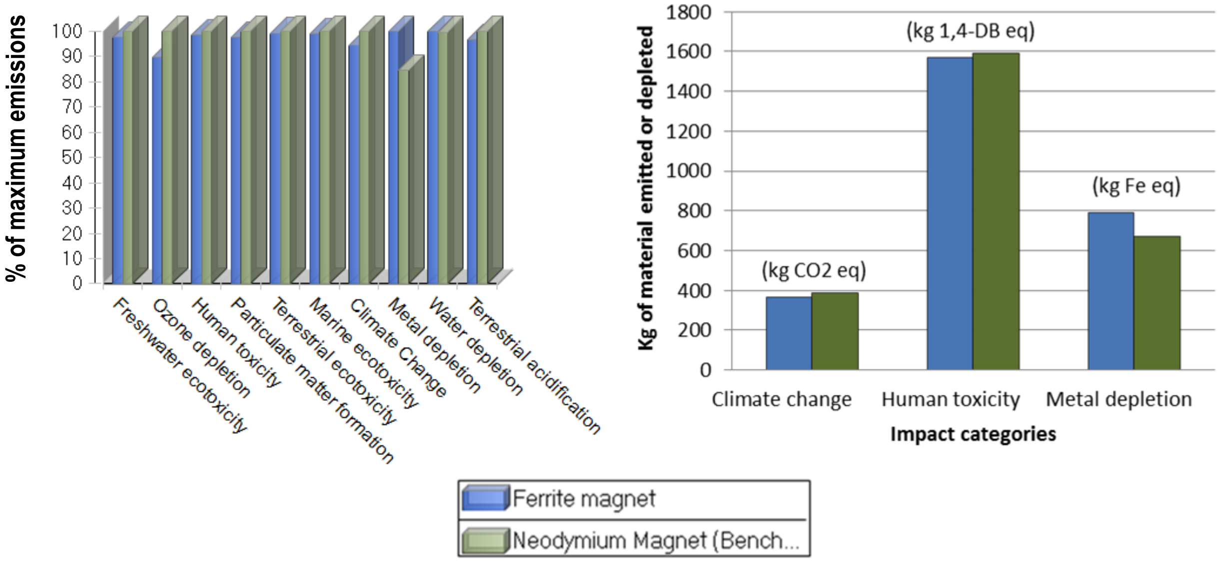

Figure 10. Comparison by percentage and absolute emissions of magnets materials

As figure 10 shows, the general environmental impact of using ferrite magnets is smaller than with the use of neodymium magnets. This is true for every impact category except for metals depletion. When observing to the amount of total emissions, it can be appreciated that the difference in consumption of Fe equivalent, impacting metal depletion category, is about 120kg, which is a significant figure. However, the overall environmental performance of using ferrite is better than with the use of neodymium, as it is evidenced by the difference of about 20kg of CO_2 eq. non emitted to the atmosphere, and around less 25kg of 1,4DB eq. affecting potential human toxicity. These differences that could be appreciated as small, become more significant when thinking about mass production of the electric motor, where the total amount of additionally generated emissions can have an important impact on the environment.

Resin materials

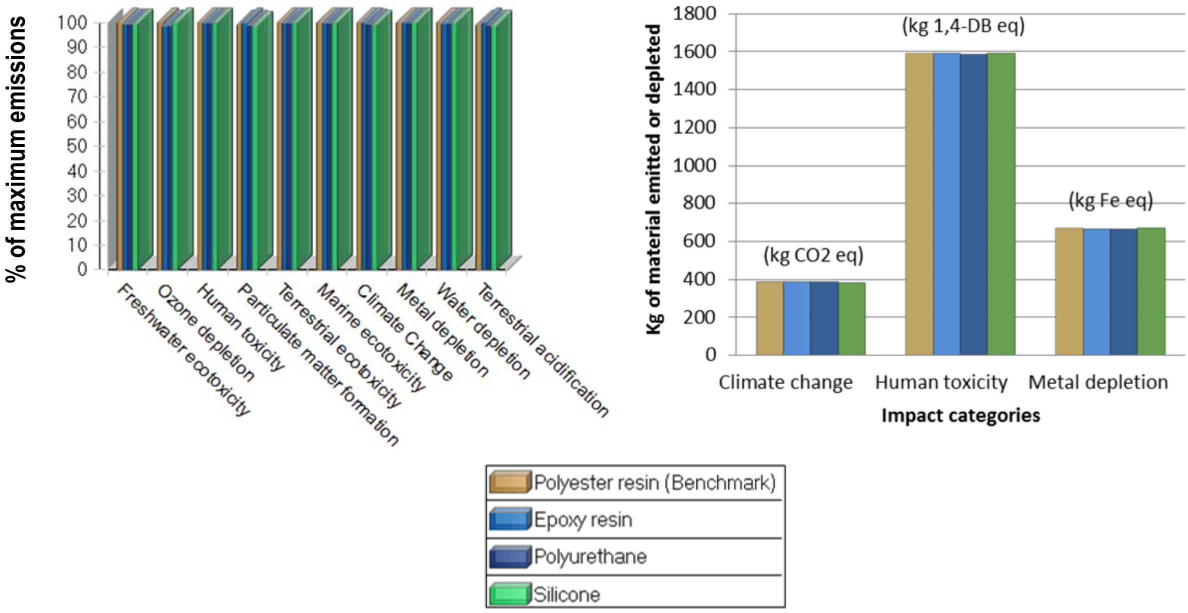

Figure 11. Comparison by percentage and absolute emissions of resins materials

In the case of resin materials, there is no evident material with better environmental performance. This is due to the small amount of these resins that are used in the motor, and similarities between their production methods. The selection between these materials should focus then in the thermal performance, and other characteristics that favor the durability of the motor.

Insulation film materials

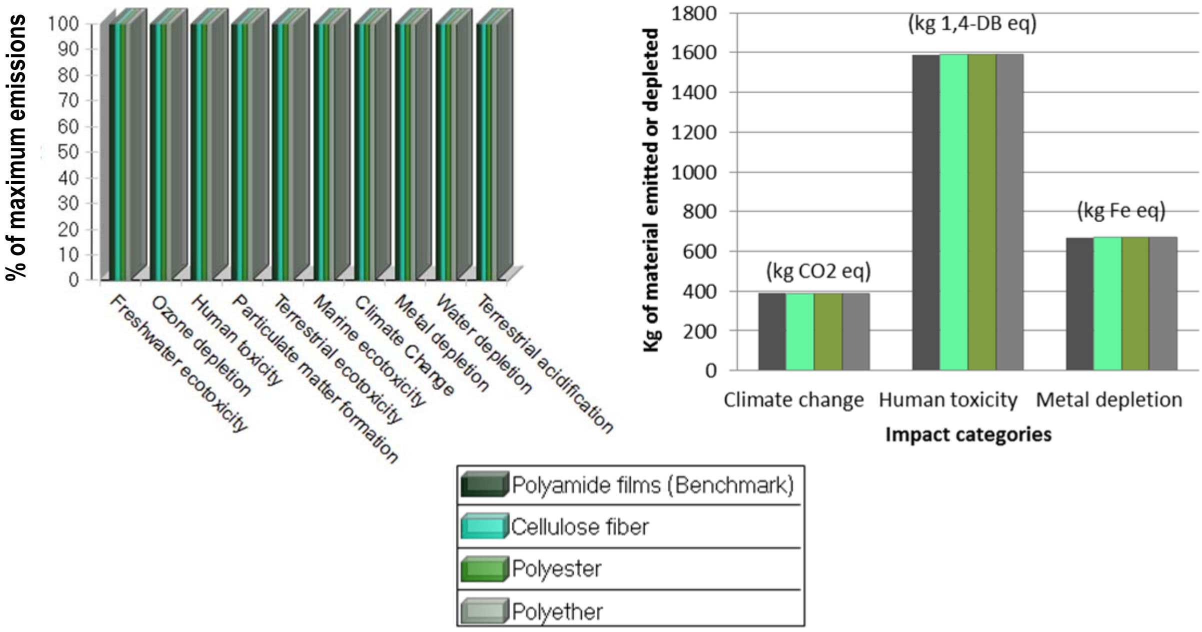

Figure 12. Comparison by percentage and absolute emissions of insulation films materials

A similar situation is found for materials used as insulation films. Even though it cannot be appreciated in the graphs, cellulose fiber generates lower emission in the order of grams, for all impact categories, comparing to other materials. For example, using cellulose fiber in the place of polyester generates 330grs less CO2 emissions. This small difference is a consequence of the small amounts of these materials required in the motor. As for resins materials, the selection of insulation films should regard matters of resistance and thermal performance.

Housing materials

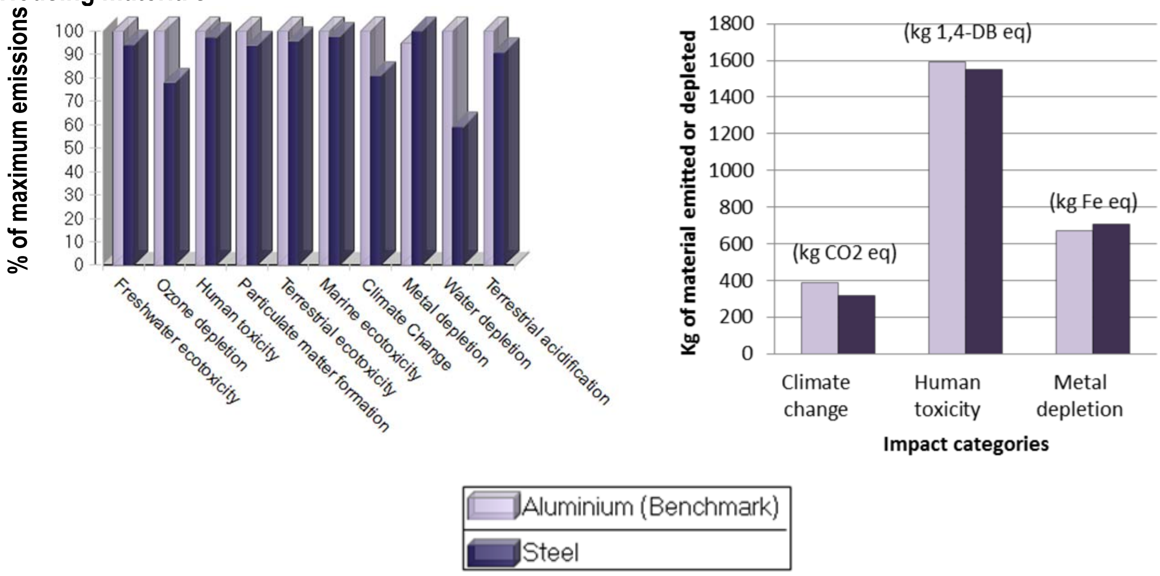

Figure 13. Comparison by percentage and absolute emissions of housing materials

Figure 13 shows that aluminium tends to be more damaging for the environment than steel. This is mainly caused by the great amount of energy used in the forming of aluminium components. Metal depletion remains the only case where aluminium is a better option than steel with a difference of about 36kg of Fe eq. saved from being consumed. For the rest of impact categories, steel represents the best choice. However, it is important to keep in mind that the housing component made of aluminium weights less, which translate to less energy consumption during use stage.

Wire materials

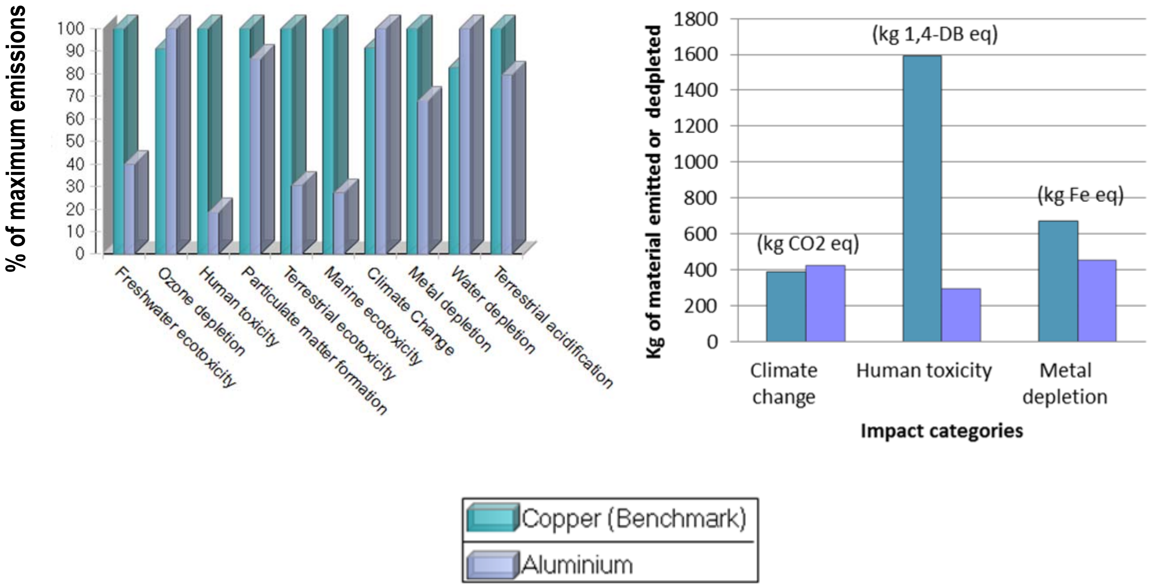

Figure 14. Comparison by percentage and absolute emissions of wire materials

Considering the majority of impact categories, the use of aluminium, in the place of copper, is more favorable for the environment. This is particularly the case when looking at the human toxicity levels offered by each one of the options. In the case of aluminium, about 1300kg of 1-4DB eq. are being avoided to risk human health. In the big majority of the cases, the use of copper will always be less favorable for the environment in terms of toxicity. Aluminium, on the other hand, generates greater emissions of CO2 eq. of around 35kg over copper. In general the use of aluminium for wingding material seems more adequate, yet it is always important to consider other magnetic performance requirements of the material before the final selection.

Conclusions

The decision for selection of materials during the design process is one that needs to consider many variables. The environmental point of view should be one of the criteria to keep in mind when choosing the materials for the components of the motor. Other criteria such as mechanical, electrical and thermal requirements are also to take part in the decision making process. As stated before, the achievement of lower energy consumption during usage stage is key for the improvement of environmental impact of the SYRM. Therefore, the selection of materials should be guided as much as possible to obtaining the highest possible efficiency, and low weight of the motor.

From material production and manufacturing of the motor, the following can be concluded:

- For magnet materials: ferrite magnets represent the most environmentally friendly option comparing to neodymium magnets.
- For resins and insulation films: the environmental impact generated by these alternative materials is very similar. The decision for selecting these materials should focus on other design requirements.
- For housing material: steel generates in overall less enviromental impact than using aluminium. However, the use of aluminium, which is less heavy, is favorable for energy consumption during usage phase.
- For wire material: copper wire is a less environmental friendly option comparing to aluminium. Mainly because of its toxicity to humans and ecosystems. However, as mentioned previously, other criteria need to be taken into consideration when choosing wingding material.

4.2 General Ecodesign recommendations

4.2.1 Selection of eco-materials

Materials selection is one of the strongest environmental drives to which Ecodesign seeks to respond.

In this section, "eco-materials" refer to "materials that possess excellent characteristics with good performance, and which can be manufactured, used, and recycled or disposed of, while having only a low impact on the environment.

In general, eco-materials include:

- recyclable materials,
- materials free from hazardous substances,
- materials manufactured with low energy consumption and in clean conditions,
- materials that maintain clean water, air, and soil and,
- materials that are very efficient and resource-saving while still offering high performance

Choosing eco-materials means taking into account the impact on the environmental all along the life cycle, from resource collection to the disposal stage.

Table 2 shows considerations that must be taken into account during the design processes for the selection of materials used in in the SYRM, additionally to the ones presented in the previous sections.

This table includes three sections including the Ecodesing focus in each of the life cycle stages, and the proposed strategies, targeted at particular for SYRM components, to improve the overall possible environmental damage of the electric motor.

Table 2. Environmental improvement strategy for selecting eco-materials. (table structure adapted from [9])

Product characteristics	Ecodesign focus		SYRM component & improvement strategy
Use of materials in the motor	Selection of low impact materials	Sensitive materials	Normally, the materials for electric motors do not have sensitive origins, i.e. materials from rainforest, endangered habitats, or materials with questionable human rights, or labor exploitation issues.
		Materials with high embodied energy or water	Component: Housing. Material: steel, aluminium. Reduce as much as possible the volume of the housing, and integrate housing and cooling system for decreased materials use. Through this it is possible to reduce energy and water used to produce the material.
		Toxic materials	Components: Insulation. Materials for resins. These are the materials with the highest relative toxicity in the motor. Its use should be restricted to the minimum necessary. If possible, the use of organic materials is suggested.
		Biodegradable materials	Component: Insulation Material: Cellulose fiber Biodegradable cellulose fiber should be the preferred option as insulation material, as long as it does not interfere with thermal requirements, or generates early ageing of the insulation system.
	Materials use	Total weight	The reduction of the volume and weight of the motor components should be taken into consideration during the design process, in order to decrease the total amount of materials required for the construction.
Use of resources for and by the product	Impact in use	Resource required during use	While the traction motor is under use, electricity supply is necessary for the powering. The efficiency of the motor has a big influence on the consumption of this resource. For this reason efficiency levels should be as high as possible.

		Use of renewable energy	Eventual charging of the vehicles batteries can be done using renewable energy
Product lifetime and end-of-life recovery	Extending initial product lifetime	Durability and strength	Adequate protection should be provided for magnetic material to prevent corrosion, heat or mechanical impact, and avoid degradation of magnetic properties. Insulating materials are important factors for the lifetime of e-machines. Their proper selection, according to thermal class, and application to the motors components should evade failures. Metallic components should be provided with adequate protection in order to avoid corrosion and wear.
	End of life systems	Disassembly	Disassembly can be enhanced by manufacturing by sub-assemblies, minimizing the number of fixed joining systems, and avoiding glues, paintings and laminates.
		Recyclability of the product or components	Materials: aluminium, steel, copper. The recycling at the end of life of these materials should be promoted.

As mentioned previously, the selection of materials for the electric motor during the design process is also to rely on the relationships between materials specifications and technical performance of the product, the economic performance of the product, as well as the environmental performance of the SYRM.

4.2.2 Ecodesign and supply chain management

Suppliers selection in Ecodesign is a process of selecting suppliers based on an environmental set of criteria. It is a useful strategy to decrease resources consumption and pollution associated to a product. For the selection of suppliers in the SyrNemo project, in particularly for task 3.2, Ecodesign criteria for identifying adequate suppliers can be used to favor the environmental friendly nature of the project.

The selection of supplier can be performed based on the following environmental criteria:

- Proximity: suppliers which are geographically close may be more readily influenced than those which are distant, and the impact due to transportation of materials or components would result smaller.

- Relationships with suppliers and their performance: seek suppliers with good quality of product, track of emissions, and resources used, well established and implemented sustainable development policy, and in general, respectful of the environment.

- Suppliers compliance with legislation: companies subscribed to voluntary and mandatory environmental legislation at national and regional level, in example, environmental management systems such as ISO 14001, and environmental certifications for recycling programs, LEED and EMAS programs, etc.

- Openness for mutual reviewing and understanding the environmental issues associated to the product, including identification of the scope for alternative materials with similar function and lower environmental impact.

- Suppliers involved with external communication of its environmental performance, in programs such as Carbon Disclosure Project (CDP), Dow Jones Sustainability Index (DJSI), etc, and with a public available targets for GHG emissions, and waste reduction.

- Availability of guidelines for acquisition of raw material that address issues such as environmental compliance, certifications, materials footprint, etc.

- Procurement of environmental friendly packing methods and transportation options.

4.2.3 Manufacturing and assembly towards recycling

For the majority of the products, several strategies can be taken, during manufacturing and assembly, in order to facilitate recycling at the end of its life. For the SyrNemo project, a series of recommendations are presented, to be kept in mind during the design process, with the objective to promote recycling of motor components:

Considerations during manufacturing:

- Minimize the number of components used in an assembly, either by integrating parts or through system re-design.

- Separate working components into modular sub-assemblies.

- Construct sub-assemblies in planes which do not affect the function of the components.

- Avoid using laminates which require separation prior to re-use.

- Avoid unnecessary painting of parts as only a small percentage of paint can contaminate and prevent an entire batch of plastic from being recycled.

- Use of pure and recyclable plastic materials.

- Reduce density of plastic material.

- Use good quality second-hand materials or recycled ones if possible.

Considerations for disassembly:

- Use appropriate connecting methods such as plug in instead of screws. Screws are faster to unfasten than nuts and bolts.

- Minimize the number of material types used in an assembly.

- Determine and clearly identify in the product the materials that can be recycled.

- The fewer fasteners are used, the better.

- Glues should be avoided.

- Building disassembly instructions into the product will help users understand how to take it apart.

4.3 European Environmental Legislation

In recent years the European Union has pushed several activities for environmental legislation forward, affecting especially the electronics and electrical industry. The most important product-related policies and legislation, concerned by the SyrNemo project, are:

– Directive 2002/96/EC on Waste Electrical & Electronic Equipment (WEEE)

– Directive 2000/53/EC on End of Life Vehicles

- Directive 2002/95/EC The Restriction of Hazardous Substances in Electrical and Electronic Equipment (ROHS)

- Directive 2005/32/EC EuP – Eco-Design of Energy-using Products Directive

Table 3 summarizes the scope, main content, and relevance of three directives for the electrical & electronics sector. Descriptions on the content of Directive 2000/53/EC on End of Life Vehicles follow the table.

Table 3 – EU legislation summary: EuP, WEEE, RoHS (extract prepared from [10] reference)

EuP	**WEEE**	**RoHS**
Target		
Optimizing the whole product life cycle Consideration of environmental effects in the life cycle phases	Improving end-of-life management for electronics Implementing extended producer responsibility	Restrictions of hazardous substances from electrical and electronics equipment (lead, mercury, cadmium, chromium-VI, PBB, PBDE)
Scope / Product groups		

In general: - products which represent a significant volume of sales and trade, involve a significant environmental impact, and present a significant potential for improvement - Product groups under discussion for implementing measures: - heating and water heating equipment - **electric motor systems** - lighting in both the domestic and tertiary sectors - domestic appliances - office equipment - consumer electronics - HVAC (heating ventilating air conditioning) systems	- Large and small household appliances - IT and telecommunications equipment - Consumer equipment - Lighting equipment - **Electrical and electronic tools** (with the exception of large-scale stationary industrial tools) - Toys, leisure and sports equipment - Medical devices - Monitoring and control instruments - Automatic dispensers	- Large and small household appliances - IT and telecommunications equipment - Consumer equipment - Lighting equipment - **Electrical and electronic tools** (with the exception of large-scale stationary industrial tools) - Toys, leisure and sports equipment - Automatic dispensers
In place since:		
Framework directive adopted in principle by Council and European Parliament in April 2005	Directive 2002/96/EC of 27 January 2003 Published in Official Journal February 13, 2003 EU member states transpose WEEE by August 13, 2005 (April 2005: deadline will be missed by most EU members)	Directive 2002/95/EC of January 27, 2003 EU member states transpose WEEE by August 13, 2005 (April 2005: deadline will be missed by most EU members)
Requirements		

Setting up an eco-profile of the product may be required by the implementing measures Design control or appropriate environmental management system in place CE marking requires EuP conformity Generic ("improvement") and specific ("limit values/ thresholds") requirements to be defined in follow-up directives	"Distributor" or "producer" are obliged to follow the requirements, not of direct relevancy for (component) suppliers Separate Collection ≥ 4 kg per inhabitant and year from households (per country) Specific recovery/recycling/reuse quotas per product category Producers finance recycling Producers are obliged to submit to recyclers all relevant information for proper recycling	Restrictions of RoHS-6 substances in all products within the scope put on the market after June 30, 2006
Ecodesign relevancy		
Product design has to be improved considering the whole product life cycle	Product design should not hinder dismantling, recovery, and reuse (priority on reuse and recycling of WEEE, their components and materials) Products should be designed for easy disassembly of critical components (PCBs, batteries, brominated flame retardants containing plastics, …) Producer has to pay for recycling, thus, recyclability is an economic issue	Product material content has to be known at least regarding RoHS-6 substances Supply chain communication needed regarding legal compliance Reduction/elimination of hazardous substances

The Directive 2000/53/EC on End of Life Vehicles aims at making vehicle dismantling and recycling more environmentally friendly, it sets clear quantified targets for reuse, recycling and recovery of vehicles and their components and pushes producers to manufacture new vehicles also with a view to their recyclability. Concerning eco-design proposes the Directive states that: The requirements for dismantling, reuse and recycling of end-of-life vehicles and their components should be integrated in the design and production of new vehicles. In addition, the directive seeks to remove gradually the hazardous substances from automobile, such as: Lead (not only from batteries but also including steel, aluminum and copper containing lead), cadmium hexavalent chromium, and mercury in bulbs and instrument panel displays etc.

5 CONCLUSION

The document provides information regarding Ecodesign strategies to guide the design process of the e-motor for SyrNemo. The Ecodesign covers recommendations for the selection of materials for the main components of the motor, selection of suppliers and manufacturing techniques. These recommendations are based on a LCA study, and the key environmental performance indicators for climate change, human and ecosystems toxicity, and metal depletion were identified. According to these indicators, different material alternatives were compared, for the magnets, resins, insulation films, housing and wire materials.

During the usage stage of the motor is when the highest environmental impact is produced by the motor. This impact is many times higher than comparing to any other life stage phase, for all the 18 impact categories considered in the study, except for metal depletion which is highest during materials production. The amount of energy consumed during the usage of the motor is key to decrease the environmental impact. A high efficient motor has a big potential to produce much less environmental, comparing to a motor of lower efficiency, especially if it uses electricity producing from a renewable source.

A reduction to minimum levels of the overall amount of materials used, while adequately fulfilling other functional requirements, it is also important to decrease the impact of the e-motor, especially for housing, magnetic core and winding components. A reduction of copper used is especially important to improve the toxicity produced to humans and ecosystems. The same case occurs for aluminium and steel components, which are very energy intensive, where a reduction of their use can improve depletion of metal resources and total GHG emitted.

For the coming Workpackages of the project, the findings and Ecodesign recommendations presented in this document shall be taken into consideration for the design of the e-motor. All other specifications and requirements for the motor presented in Workpackage 2 are also to be taken into consideration as criteria for the selection of materials, and components design.

6 REFERENCES

[1] I. S. ISO 14040, "Environmental Management - Life Cycle Assessment - Principles and Frameworks," 2006.

[2] I. S. ISO 14044, "INTERNATIONAL STANDARD assessment — Requirements and," 2006.

[3] European Commission - Joint Research Centre - Institute for Environment and Sustainability, *International Reference Life Cycle Data System (ILCD) Handbook - Recommendations for Life Cycle Impact Assessment in the European Context*. 2011.

[4] Habermacher F. "Modelling Material Inventories and Environmental Impacts of Electric Passenger Cars", Department of Environmental Sciences, ETH Zurich, 2011.

[5] 1 http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database [Last visit March 2014]

[6] M. Messagie, Environmental performance of electric vehicles, a life cycle assessment approach, Thesis submitted in fulfillment of the requirements for the award of the degree of doctor in engineering, Vrije Universiteit Brussel VUBPRESS, 2013.

[7] U. S. Environmental Protection Agency and U.S. Department of Energy (2012-12-06). "Model Year 2013 Fuel Economy Guide". Fueleconomy.gov. Retrieved 2014-25-03.

[8] J. Van Mierlo, F. Boureima, N. Sergeant, V. Wyen, M. Messagie, L. Govaerts, T. Denys, M. Vanderschaeghe, C. Macharis, L. Turcksin, W. Hecq, M. Englert, F. Lecrombs, F. Klopfert, B. De Caevel and M. de Vos, " Clean Vehicle Research: LCA and policy measures (Clever), Final report Phase one", Belspo, 2009.

[9] United Nations Environment Programme UNEP, "Design for Sustainability. A Step-by-Step Approach", ISBN: 92-807-2711-7, 2009.

[10] Karsten Schischke, Marcel Hagelüken, Gregor Steffenhagen, "An Introduction to EcoDesign Strategies – Why, what and how?", Fraunhofer IZM, Berlin, Germany, 2005.

7 APPENDIX

Materials and processes needed for the production of a SYRM*

Materials and processes	Amount	Unit
Aluminium, production mix, at plan/RER U	14,21	Kg
Sheet rolling, aluminium/ RER U	14,21	Kg
Steel, low-alloyed, at plant/ RER U	94,51	Kg
Silicone product, at plant/ RER U	2,92	Kg
Nylon 6, at plant/ RER U	0,06	Kg
Cellulose fiber, inclusive blowing in, at plant/ CH	0,06	Kg
Copper, at regional storage/RER U	6,66	Kg
Wire drawing, copper/RER U	6,66	Kg
Polyester resin, unsaturated, at plant/ RER U	1,25	Kg
Chromium steel 18/8, at plant/ RER U	3,64	Kg
Neodymium oxide, at plant/ GLO U	0,68	Kg
Pig iron, at plant/GLO U	1,59	Kg
Boric oxide, at plant/GLO U	0,07	Kg
Epoxy resin, liquid, at plant/ RER U	0,48	Kg
Iron-nickel-chromium alloy, at plant/ RER U	1,38	Kg
Lubricating oil, at plant/ RER U	0,06	Kg
Tap water, at user/ RER U	0,04	Kg
Ethylene glycol, at plant, RER	0,04	Kg
Electricity, EU 27 Electricity mix 2011 [kWh]	62,74	kWh
Heat, natural gas, at industrial furnace	52,92	kWh

* Table includes materials and energy necessary for the production of a 45kW SYRM

EU27 2011 Electricity mix

Energy	Amount	Unit
Geothermal energy	0,00200	kWh
Wind power	0,05700	kWh
Hard coal	0,31210	kWh
Hydropower	0,10600	kWh
Natural gas	0,18680	kWh
Nuclear	0,27600	kWh
Oil	0,04410	kWh
Photovoltaics	0,01500	kWh

Recycling and MSWI disposal of a 45kW SYRM

Materials disposal	Amount	Unit
Aluminium, secondary, from old scrap, at plant, RER, [kg]	13,22	Kg
Steel, electric, un- and low-alloyed, at plant, RER, [kg]	97,17	Kg
Copper, secondary, from electronic and electric scrap recycling, at refinery, SE, [kg]	5,86	Kg
Disposal, plastics, mixture, 15.3% water, to municipal incineration, CH, [kg]	4,77	Kg
Disposal, aluminium in car shredder residue, 0% water, to municipal incineration, CH, [kg]	0,99	Kg
Disposal, steel in car shredder residue, 0% water, to municipal incineration, CH, [kg]	0,98	Kg
Disposal, copper in car shredder residue, 0% water, to municipal incineration, CH, [kg]	0,8	Kg