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R&D AND LCA ACROSS THE SUPPLY CHAIN: CHOICE OF UNSATURATED POLYESTER RESINS FOR CC-GRP PIPE SYSTEMS

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Abstract. In today's economy increased attention is given towards re-using of available resources and using of resources which are re-generable, to evaluate and reduce the impact on the environment. For the polymer industry, the development of alternative and renewable raw materials represents an essential task. The study evaluates the different choices of unsaturated polyester resins (UPR) for production of centrifugally-cast glass reinforced pipe (cc-GRP) systems.The environmental impacts of three types of resin were evaluated and compared. The resins are: UPR standard, UPR containing recycled PET material (rPET-UPR) and UPR containing bio-sourced material (BIO-UPR).The analysis focuses on comparing the variations in environmental indicators caused by resin selection for three increasingly complex product layers (Base plate of cc-GRP shaft, cc-GRP Shaft and 1km cc-GRP Pipe-system). The study equally provides an insight onto R&D and LCA collaboration across the supply-chain. One of the main challenges in LCA today is using specific data from the suppliers instead of generic data. The paper indicates how LCA tools and established R&D processes can be employed to transfer LCA calculations across the supply-chain.BIO-UPR and rPET-UPR are alternatives which are realistic in terms of costs and which ensure the required quality for the manufactured products. rPET-UPR can be used for production of complete pipe systems, with positive environmental indicators. Mechanical proprieties of BIO-UPR restrict its usability and use of this resin presents similarities with the debate regarding use of bio-diesel.

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Introduction

Companies today are expected to work toward achieving environmental responsibility across the supply chain and to evaluate the life-cycle environmental impacts of products. Products manufactured within the supply chain should be evaluated from an environmental point of view regarding their design, distribution, use, disposal and recycling. Many companies however do not have a coherent and systematic approach for incorporating life cycle analysis (LCA) in their business relationships. Even though internal and external reports may be pursued, deeper cooperation across the value chain is often reduced to data transfer or exchange of readily available information without necessarily involving common work or joint research and development (R&D) processes. On the other hand, the analysis of environmental impacts of products has been gaining attention due to increasing refinement of life cycle analysis methods and tools. Thus, it may be increasingly easier for companies to deepen collaboration on LCA considering that related assessment tools are gradually becoming more user friendly and that the existing knowledge base is increasing.

Per ISO 14044:2006 “Environmental management - Life cycle assessment - Requirements and guidelines”, “specific data should be used for those processes that contribute most the mass and energy flows in the system”. The Technical Report CEN/TR 15941:2010 “Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data” indicates that “specific data for a certain product or process should be used”.

“Often, however, such specific data are not available and the practitioner has to identify information from other sources; generic data then replaces specific data”. Per CEN/TR 15941:2010 “generic data should never replace specific data if specific data are available”. Furthermore, EN 15804:2012 "Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products" states that, “as a general rule, specific data derived from specific production processes or average data derived from specific production processes shall be the first choice” as basis for calculation. The LCA normative references cited above indicate that using specific data (data from direct suppliers) represents good practice when it comes to life cycle assessment. This is at the same time one of the biggest challenges, as a limited number of companies today have readily available life cycle inventory (LCI) datasets.

In the case of HOBAS and REICHHOLD inclusion of life cycle assessment in material evaluation was possible on basis of the long-term close collaboration of the R&D departments of both companies. This indicates that an already existing product development collaboration within the supply-chain may constitute a favorable context to adding LCA analysis.

The present study evaluates three different choices of unsaturated polyester resins (UPR) for cc-GRP pipe systems, from a LCA perspective. To this purpose, the environmental impacts GRP products manufactured with three types of resin were evaluated and compared. These resins are: standard UPR, UPR resin containing recycled PET material (denoted rPET-UPR) and UPR resin containing bio-sourced material (denoted BIO-UPR).

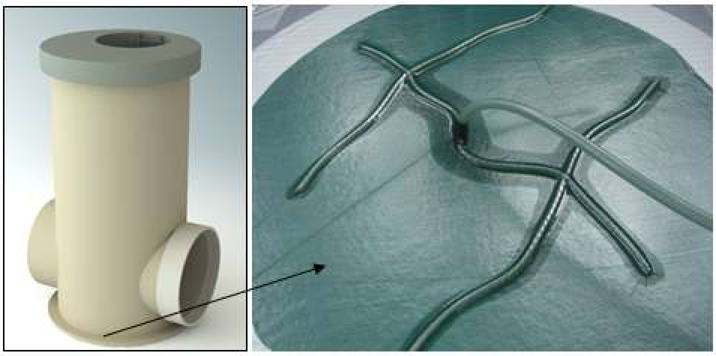

Fig. 1.Base Plate (part of Shaft) manufactured with BIO-UPR by vacuum infusion

An important step in choosing resins is to determine the possible applications and to ensure that final product properties be maintained. In addition, the choice of resin should also prove its economic functionality, so that products can be manufactured and be made available to market at reasonable production costs. Therefore, an initial internal assessment was performed by HOBAS to determine the applicability of rPET-UPR, respectively BIO-UPR. It was assumed for this study that rPET-UPR may be employed to manufacture cc-GRP pipe systems. One possible application, as presented in this study, is sewage systems. Some of the raw materials used in polyester resin production process can be derived from polyethylene terephthalate bottles. REICHHOLD has developed an innovative technology to substitute up to 30 w-% of typical raw materials with recycled post-consumer or post-industrial PET material.

BIO-UPR is a medium reactivity orthophthalic resin which is produced with addition of renewable resources originated from soybean oil. In recent years, there has been increasing interest in the development of thermosetting resins using bio-based products that can reduce or potentially eliminate the usage of petroleum based hydrocarbons. The BIO-UPR resin was tested in the HOBAS laboratory to determine possible applications. Based on product tests and manufacturing trials, it was determined that BIO-UPR resin can be successfully employed in production of GRP Shafts, namely to produce the Shaft Base Plate (environmental impact indicators are further presented in this study). The Shaft Base Plate was produced based on vacuum production process. This design eases the way of manufacturing and improves the repeatability and is at the same time a very lean production technology.

1. METHODS

The goal of this study is to compare the environmental impacts of standard UPR resin (reference) with rPET-UPR resin and BIO-UPR resin, as employed in HOBAS products. Based on product and manufacturing trials, BIO-UPR can be employed to produce the Base Plate of GRP Shafts. To make the comparisons more relevant two declared units (cradle to gate) and one functional unit (cradle to cradle) were defined: one typical unit Base Plate of GRP Shaft DN 1000 mm and one typical unit GRP Shaft DN 1000 mm. The functional unit was defined as 1000 meters typical buried sewage non-pressure cc-GRP Pipe system of pipes DN 400 mm with couplings and Shafts DN 1000 mm, with a reference service life of 100 years. The different levels of calculation are depicted in Fig. 2 below.

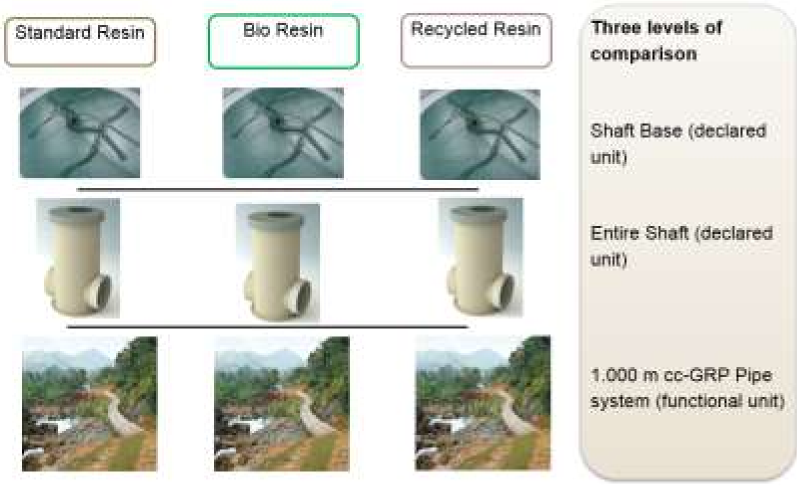

Fig. 2. Levels of comparison (declared and functional units)

System boundaries were defined in accord with ISO 14040-44 and EN 15804. Details about each stage is presented in the Table 1 below.

Table 1. System boundaries for the functional and declared units

Stage	Detail
Raw material supply (A1)	Included. Main raw materials are: unsaturated polyester resin, fibre glass, sand and filler. To these additives are added. Inclusive packaging of main raw materials.
Transportation product stage (A2)	Included.
Manufacturing (A3)	Included. Inclusive use of ancillary products for manufacturing, energy flows (electricity, natural gas and diesel), water consumption and packaging of products.
Transportation construction installation stage (A4)	Included. Installation of the pipe system was calculated per ÖNORM EN 1610 Construction and testing of drains and sewers. The installation phase includes materials and activities connected to installation of the piping systems at location, excavating a trench of 1000 m, placing the components per requirements and backfilling of the trench. This includes use of machines and lifting equipment, consumption of machinery, re-filling material (gravel), transportation of products / transportation of wastes from the installation site / transportation of gravel from the mine to the installation site/ transportation of local mass to the landfill and waste management from the installation site.
Use stage (B1 – B5)	The use stage is calculated for 1.000 meters of GRP pipe system during 100 years. Energy required to transport water in the piping system (i.e. pumps) is excluded from the LCA as the piping system is based on gravity. Flushing or cleaning activities of the pipes during the operation stage are excluded from the analysis, as the activity is assumed to have minor impact on the total results. It is assumed that no hazardous or toxic materials are used for cleaning. It is assumed that maintenance activities, replacements or repairs of pipes not will be necessary during 100 years.
End of life stage (C1 – C4)	It is assumed that the most likely end of life scenario will be that the pipes are left in the ground after use.
Issues beyond the system boundary.	Not included.

2. CALCULATION BACKGROUND AND SUPPLY -CHAIN COLLABORATION

2.1 Calculation background

The LCA calculations account for 99,9% product mass. For some materials (i.e. additives and ancillary) specific LCA datasets were not readily available at the time of the calculation and these were replaced with generic datasets. Sensitivity analysis was performed to evaluate the influence of these materials on the results. Input material and energy flows comprising more than 1% of the total mass or contributing more than 1% to primary energy consumption are considered. The production inputs and process-specific waste and process emissions were considered. Input material flows below 1% mass were also included; however, packaging of additives and ancillary materials (material flows under 1%) was not included. Capital goods were included.

The geographical scope of the study is in Europe. Pipes are produced at the HOBAS European factories in Germany, Poland, Austria and Romania. Pipe DN 400 mm with coupling is calculated as an average European pipe (all locations), Shaft (including Base Plate) are calculated for the Austrian factory. The period is that of year 2012; data from production facilities was collected from the year 2012. Generic data are from the Ecoinvent Database (Version 2.2). Site-specific data have been collected to characterize the production processes and their related physical flows. Data collected from suppliers (LCA data sets) includes resin and glass-fiber.

2.2. Supply-chain LCA collaboration

Calculations for HOBAS and REICHHOLD models were performed with Umberto for LCA developed by ifu Hamburg. The software represents the collaborative tool for LCA modeling between the two companies in the value chain (input material, resins = REICHHOLD and end-product, cc-GRP pipe systems = HOBAS). Using the same calculation tool enabled data exchange easily either in Umberto or Ecospold formats. Visualization, valuation of results and easy exchange of datasets constituted key advantages in joining efforts between two companies and especially in the field of R&D. Calculated datasets (products) were exported and, equally, the environmental impacts were readily obtained with the valuation function. The same function was equally used to verify received datasets, to validate the received information. Adopting a LCA collaborative tool and internalizing it constitutes sound premises for long term sustainability assessment. The association of the LCA tool with R&D

departments allows evaluating the environmental impacts and benefits of products from the very first phases of product development.

Another key aspect of collaboration is the sharing of proprietary data. Concerns may be issued that if LCA product models are shared, then proprietary data may be thus also transmitted. Even if confidentiality agreements are in place, there is always caution to sharing data and models that are specific and part of the core competence of a company.

The advantage with a LCA collaborative tool is that while models may be discussed together, data which is transmitted across the supply-chain and used by the next company in the calculation of its own products can be exported as a typical life cycle inventory (LCI) balance sheet. Within the balance sheet all required material flows for the LCA calculations are included. However, it is not possible to identify the structure and the specific proprietary data in the initial calculation model. Thus, confidential internal data remains with the producer, which is an important aspect that needs to be addressed. Deeper collaboration on the other hand is equally possible and permits reviewing of the models in detail, if producers in the supply chain agree to proceed so.

Finally, scenario development emphasizes connection with R&D and technical departments, new products and raw materials can be tested and new data integrated in already existing models. Variation of multiple parameters as well as calculation of various types of sensitivity analysis were performed. Thus, environmental impacts can be assessed readily and early in the development stage. These possibilities were unavailable just a few years ago.

3. RESULTS

BIO-UPR can so far be used for the Base Plate of the Shaft (30% weight BIO-UPR). Therefore, a first analysis at this level is most relevant for this resin. rPET-UPR and standard UPR resin can be used for all types of products (Base Plate, Shaft and Pipe System). In a second step, the Base Plate is integrated in the Shaft. At this level, differences in environmental impact assessment caused by the BIO-UPR are noticeable in a lesser extent as Base Plate becomes part of a bigger element, the Shaft (4% weight BIO-UPR). Finally, impact of the BIO-UPR can be detected at the System level, albeit in an even lesser extent as pipes with couplings are added to the calculation (0,05% weight BIO-UPR). The results are compared against standard UPR resin, thus allowing to position the rPET-UPR and the BIO-UPR as possible alternatives.

The results at Base Plate level clearly indicate differences in the environmental impacts of the Base Plate manufactured with BIO-UPR, as compared with standard UPR and rPET-UPR. If results for the latter two resins are quite close, results for the Base Plate with BIO-UPR present interesting variations. For instance, CO2-eq. emissions are similar but indicators such as "total renewable energy", "net use of fresh water", "depletion of abiotic resources", "stratospheric ozone depletion" and "photochemical ozone creation (POCP)" vary considerably in case of BIO-UPR.

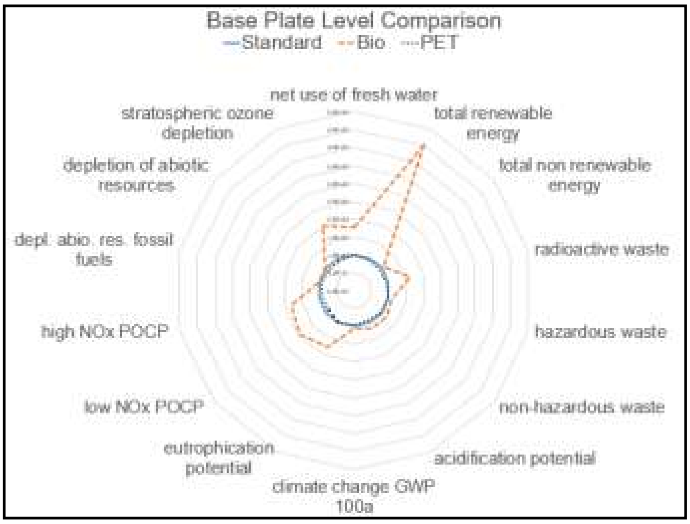

Fig. 3. Base Plate Level comparison

The results of the comparison for the Shaft product and 1000m Pipe System are presented in the Fig. 4 and 5 below.

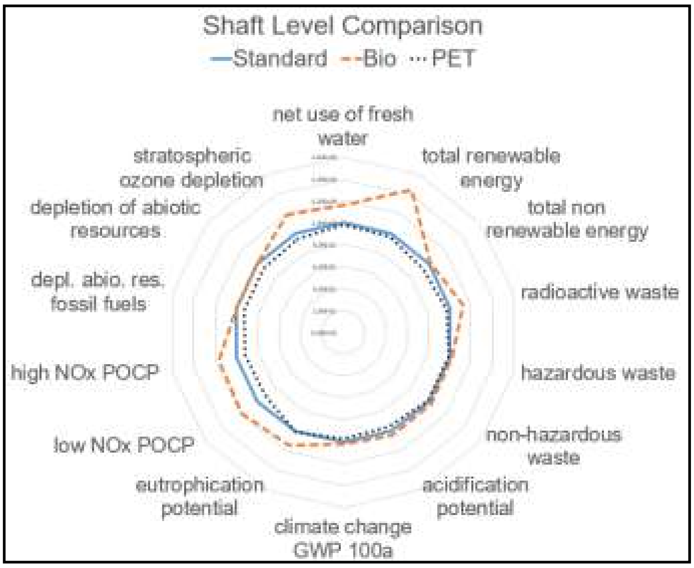

Fig. 4. Shaft Level Comparison

By comparing the three products, it can be noticed that results are like the Base Plate level but subdued as the BIO-UPR Base Plate becomes a part of the Shaft. Environmental results for the Shaft produced with rPET-UPR are similar and slightly better with the standard UPR Shaft.

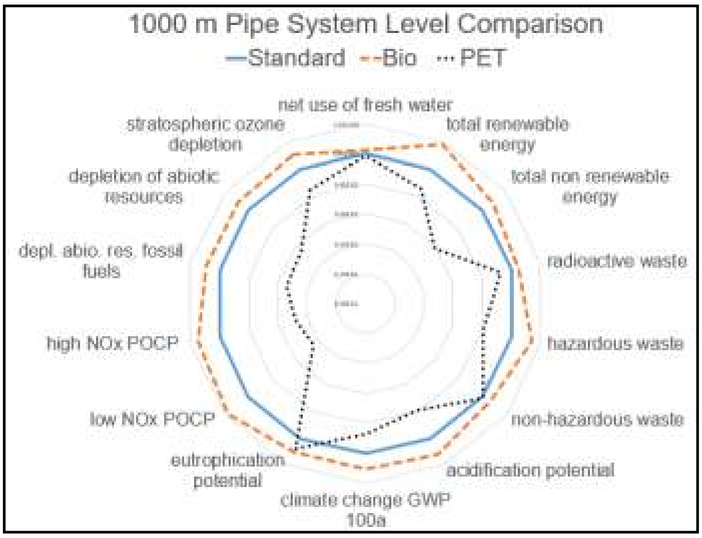

Fig. 5. Pipe System Level Comparison

Environmental impacts for the 1000m Pipe System are also determined for three scenarios: Pipe System produced with standard UPR resin, Pipe system produced with standard UPR while the Base Plate for Shafts is produced with BIO-UPR and, finally, Pipe system produced with rPET-UPR including the Base Plate. By comparing the three systems it can be noticed that results are within the same trend as previously analyzed regarding use of BIO-UPR (several increases of environmental indicators) and of rPET-UPR (several decreases of environmental indicators).

4. DISCUSSIONS

By using BIO-UPR, the environmental impact indicators for the Base Plate increase. It is important to keep in mind that BIO-based component is just one of many components used to produce the BIO-UPR resin. As analysis showed, it is not the BIO component directly but also other ingredients of the resin which are negatively affecting some of environmental indicators. Particularly, high share of Styrene and Propylene Glycol (PG) in this resin tend to increase some values (i.e. Global Warming Potential –GWP- calculated for PG or Styrene is twice as high as for bio-component used in production). This aspect is detailed in Table 2 below, presenting the impact of selected raw materials on GWP 100a values. Knowing this, it is possible to design new bio-based resins in the future having a much more favorable sustainability footprint than today.

Table 2. Normalized %-contributions of selected raw materials to GWP 100a [kg CO2-eq.] for BIO-UPR resin.

Raw material	GWP 100a for specific raw materials in 1 kg of BIO-UPR	%-contribution for GWP 100a for 1 kg resin	Weight %	Normalized %contribution
Styrene Monomer (SM)	1,31	36,13	30,14	1,20
Propylene Glycol (PG)	1,11	30,41	24,65	1,23
Fatty acids	0,28	7,59	12,12	0,63

Directly pertaining to BIO-UPR, the indicator with most variation is “total renewable energy” (bio-mass embedded energy). This indicator varies with 450% as compared with the Base Plate produced with Standard resin. Consumption of renewable energy is however today increasingly prioritized. Per statistics, “in 2011 energy from renewable sources was estimated to have contributed 13.0% of gross final energy consumption in the EU27, compared with 7.9% in 2004 and 12.1% in 2010”. Furthermore, “the share of renewables in gross final energy consumption is one of the headline indicators of the Europe 2020 strategy. The target for the EU27 to be reached by 2020 is a share of 20% renewable energy use in gross final energy consumption” (Urhausen, 2013). It may be argued that, on one hand with use of BIO-UPR the consumption of renewable energy increases but on the other hand renewable energy provides definite advantages (it does not consume limited and more polluting resources such as fossil fuels). Therefore, the question: if renewable energy is a priority and is preferable to conventional energy sources, is it then a better choice to consume more renewable energy than conventional fossil fuels to obtain the same product?

Another aspect, equally interesting, is the increase in water consumption for the product with BIO-UPR. This is not a surprise as the BIO-UPR is obtained through vegetable mass. The question here may be not only the consumption of water but also what happens with the water. If water is part of the agricultural cycle and returns to nature, to which degree does increased consumption of water raises an issue? On one hand, increasing biofuels production may “impact water quality due to the use of agro-chemicals and through harmful substances produced in feedstock processing and conversion” (Ajanovic, 2010). On the other hand, to reduce water consumption “biofuel feedstock under irrigated conditions could be discouraged and feedstock appropriate for rain-fed cultivation could be used” (Fischer et al., 2009).

Increase of the indicator “depletion of abiotic resources” is equally interesting as abiotic resources include crude oil, metals ores (i.e. gold, iron, copper, silver, etc.) and mineral compounds. Another indicator with a relevant increase is “photochemical ozone creation” (POCP). Generally, the main source of emissions for this indicator is fuel combustion followed by VOCs (volatile organic compounds). VOCs are commonly emitted from solvents, which is in this case related to current technology in production of BIO-UPR. Values for the “stratospheric ozone depletion” indicator likely also relate to this issue.

Considering the use of BIO-UPR as an alternative may also connect to the biofuels controversy. The increase of biofuels consumption takes place within the present “unsustainable pattern of energy use, which is characterized by a profligate (mis-)use of abundant and cheap fossil fuels” (Sachs, 2007). The unsustainability of the present energy consumption trends can be analyzed in the Reference Scenario of global energy demand to 2030. The demand is expected to increase by just over a half between 2007 and 2030 – an average annual rate of 1.6 per cent. Fossil fuels will likely remain the dominant source of energy, accounting for 83 per cent of the overall increase in energy demand between 2004 and 2030. The share of biomass will decrease a little, accounting for 10 per cent of total primary energy demand in 2030, since the traditional forms of biomass use will decrease, offsetting the growing use of biofuels and biomass-based electrical power. The share of all other renewable energy technologies will likely increase from 0.5 per cent today to only 1.7 per cent in 2030" (Birol and Mandil, 2007). Use of biofuels raises the dilemma of diverting farmland or crops for fuels production to the detriment of the food supply (the issue was increasingly debated during the 2006 - 2008 commodity price boom).

On the other hand, biofuels may also represent an opportunity, "an important tool with which to combat hunger and poverty" (Graziano da Silva, 2007) with an "enormous potential for accelerating growth in many of the world's poorest countries, fostering agriculture and providing modern energy to one third of the world's population" (Diouf, 2007). For example, a study of the World Bank concluded that "the effect of biofuels on food prices [in the 2006 – 2008 period] has not been as large as originally thought" (Baffes and Haniotis, 2010).

One in-depth approach to the issue of BIO-UPR is to globally assess the results, considering all environmental impacts. For example, impacts on climate change are similar for Standard resin and BIO-UPR but indicators such as "renewable energy" consumption, "depletion of abiotic resources", "photochemical ozone creation" and "eutrophication" (the latter due to the use of fertilizers) are higher for BIO-UPR. In addition, normalized results indicate further that among considered indicators, "depletion of abiotic resources" may be one of the key values even if the variation of this indicator is not as significant as of the other indicators mentioned above.

Regarding the Shaft, the indicators which vary most for the Shaft with BIO-UPR are "total renewable energy", "photochemical ozone creation" (POCP), "net use of fresh water" and "eutrophication potential". These indicators have been discussed in regard with the BIO-UPR for the Base Plate. The indicators which vary most for the Shaft with rPET-UPR, in the sense that environmental impacts are in this case reduced, are "total renewable energy", "photochemical ozone creation" (POCP), "depletion of abiotic resources" and "depletion of abiotic resources fossil fuels". In general, environmental results for the Shaft produced with rPET-UPR are similar, slightly better as compared with the standard UPR resin Shaft. Again, use of rPET-UPR for the product seems to be the environmentally friendly choice.

For the Pipe System level, where the Shafts include Base Plates produced with BIO-UPR there is increased consumption notably for the "total renewable energy" indicator. However, it can be noticed that, for one km pipe system, the variation of impacts when BIO-UPR is used for manufacturing is less significant due to the small mass proportion of the BIO component in the entire system.

The Pipe System produced with rPET-UPR presents altogether good values, with environmental impacts below those of the System manufactured with standard UPR. Most variation, in the positive sense of reduced environmental indicators, is noted for “photochemical ozone creation” (POCP), “total renewable energy”, “depletion of abiotic resources” and “depletion of abiotic resources fossil fuels”.

Conclusions

Choice of BIO-UPR seems to be a more complex choice and can hardly be reduced to the simple question of, for example, which resin generates more CO2-eq emissions for the product. In a first step, increased consumption of “renewable energy”, “water consumption”, “stratospheric ozone depletion” and “photochemical ozone creation” are noticed from the calculation. This places the use of BIO-UPR in the mainstream concern of sustainability today, associated with biofuels, where such alternatives need to be thoroughly assessed for their benefits as well as for their possible disadvantages. However, the exploration of alternatives to limited (fossil) resources and the common efforts to identify and provide applicable and cost-effective solutions to existing raw materials is a fruitful and necessary step. Regarding use of BIO-UPR for the Shaft and 1000m Pipe System, it can be noticed that variation amplitude is lower as compared with the Base Plate.

It can be observed that the use of rPET-UPR constitutes an interesting alternative, which may definitively be a valid choice from an environmental perspective. rPET-UPR has an overall excellent behavior in terms of mechanical and environmental performance. BIO-UPR, while in its incipient stage in finding applications in the GRP Pipe Systems poses more challenges and may constitute a possible choice, given that its environmental impacts are pondered at different levels (Shaft Base, Shafts, and Pipe System).

Identification and evaluation of environmental alternatives is especially significant for the constructed space as it intertwines with the nature around us. Enhancing R&D with LCA assessment capabilities across the supply chain is one of the best choices which can be met today in ensuring sustainability. This may not necessarily point out to just comparisons about products in terms of environmental impact categories but to a more profound and aware analysis as well as identification of long-term solutions that provide most functionality while respecting the surrounding environment.

References

Ajanovic, A., 2010. *Biofuels versus food production: Does biofuels production increase food prices?*, Energy, 5

Baffes, J., Haniotis T., 2010. *Placing the 2006/08 Commodity Price Boom into Perspective*, Policy Research Working Paper 5371, World Bank, documents.worldbank.org/curated/en/home, 2

Birol F., Mandil C., 2007. *IEA scenarios, what role for biofuels in the global energy scene?* Revue des Ingénieurs, 12–14

BS EN 15804, 2012. *Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products*, British Standards Institute, London, 26

CEN/TR 15941, 2010. *Sustainability of construction works - Environmental product declarations - Methodology for selection and use of generic data*, European Committee for Standardization (CEN), 7

Diouf J., 2007. *Biofuels should benefit the poor, not the rich*. Financial Time.

Fischer G. et al., 2009. *Biofuels and food security*, OFID Pamphlet Series 39, International Institute for Applied system Analysis (IIASA)

ISO 14044, 2006. *Environmental management -- Life cycle assessment -- Requirements and guidelines,* International Organization for Standardization, Geneva, 10.

Sachs I., 2007. *The Biofuels Controversy*, United Nations Conference on Trade and Development, DITC - International Trade: Trade, Environment and Development, UNCTAD, 3-7.

Graziano da Silva J., 2007. *Biocombustiveis para os pobres*. Ecodebate, [www.ecodebate.com.br]

NPCR 019, 2012. *Piping systems for use for sewage and storm water (under gravity).* Norwegian EPD Foundation, [www.epd-norge.no/]

Urhausen J., 2013. *Renewable energy - Share of renewable energy up to 13% of energy consumption in the EU27 in 2011*, Eurostat Press Office, [europa.eu/rapid/press-release_STAT-13-65_en.htm], 2