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# LCA of different energy sources for a water purification plant in Burkina Fasso

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**ABSTRACT**

This article presents a natural coagulant obtained from *Moringa oleifera* seeds used to reduce water turbidity. The residue generated by an oil extraction plant from *M. oleifera* seeds is valuated as coagulant in an automatized water purification plant that needs power supply. The main objective of this study is to find the most suitable and sustainable power supply option with regards to a specific zone of Burkina Faso. This article discusses the possibility to deploy a sustainable system providing water purification and electricity to a village of Burkina Faso. Three scenarios are considered to power up the water purification plant (A: electricity grid, B: diesel generator and C: solar panels supported by second life EV batteries). The environmental impact of these three scenarios is done following the life cycle assessment (LCA) methodology based on energy and resources consumption during the material extraction, elements manufacturing, use and dismantle phases. The less pollutant option for this case in Burkina Faso is the "solar panels supported by second life EV batteries". In comparison to the other scenarios, this system entails a significant reduction of the environmental impact, mainly in the categories of climate change and fossil depletion.

*Keywords:* Life cycle assessment; Energy sources; Water purification plant

## 1. Introduction

This article presents the reality of many African villages where access to drinking water and electricity is unthinkable. Aluminum sulphate, ferric chloride, polyaluminum chloride are the most commonly used coagulants in water treatments. However, these coagulants produce chemical sludge, which is hazardous. Hence, a biodegradable coagulant is suggested to be a better alternative [1]. In contrast to chemical coagulants, plant–based natural coagulants are safe, eco–friendly, generally toxic free and are easy to find in African villages. Natural coagulants are known for their efficiency in reducing turbidity but little is known about the characteristics and properties of the resultant flocs formed [2]. *M. oleifera* is a multipurpose tree native to Northern India that now grows widely throughout the tropics. *M. oleifera* seed extract is a water–soluble protein with a net positive charge, the coagulation components are cationic peptides and the high density of glutamine residues could favor floc formation through bonding among proteins coating the particles [3].

Previous studies showed the valuation of the residue generated by the oil extraction plant from *M. oleifera* seed. In these study a life cycle assessment (LCA) compared the environmental impact of conventional chemical coagulants against the coagulant obtained from *M. oleifera* [4].

The residual cake produced during the oil extraction process from *M. oleifera* maintains the positively charged protein of the seed, which enables the capture of suspended particles in the water. Such coagulant–flocculant properties enables the elimination of turbidity in the process of water purification. Previous study cases demonstrated that the same amount (100 mg/L) of aluminum sulfate coagulant and *M. oleifera* coagulant is required to reduce water turbidity to

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levels within the International guidelines (<5 NTU), but the energy consumption to produce one kg of aluminum sulfate ($Al_2(SO_4)_3$) is almost 40% greater than for a *M. oleifera*–based coagulant. Furthermore, carbon dioxide ($CO_2$) emissions associated with alum are 80% higher than those of the *M. oleifera*–based coagulant. In addition to turbidity removal, with lower energy consumption and reduced $CO_2$ emissions, the coagulant derived from the residual oil cake does not provoke any alterations to water pH or conductivity and, therefore, does not require any additional readjustment of these parameters.

Moreover, it was demonstrated that the required dose of *M. oleifera* can be reduced by adding NaCl, while enhancing the effectiveness of the *M. oleifera* exponentially. This factor is relevant if the region where the plant should be allocated counts on abundant amounts or access to salt [4].

To perform this purification method in a real scale case based on its application in the region of Burkina Faso, two purification plant were designed. The first design has no energy inputs apart from human power, while the second design is automated, needing electricity to power it up. In both cases, the simplicity of the design allows them to be transportable. The choice of one or another design depends on the particularities of each village or location where the plant should be installed (number of inhabitants, access to power supplies, electricity grid connection, etc.). Assuming an economic growth from this project together with other activities, it has sense to study the integration of several power sources to run the automatic plant, and observe which one is more sustainable.

Fig. 1 shows both alternatives, the manual plant (on the top–left side) and the automated plant (bottom–left side) together with three power source scenarios (A: electricity grid, B: diesel generator and C: solar panels supported by second life EV batteries).

Fig. 2 shows a picture of the prototype plant. It can be observed that the plant, although automatic, can work on a manual mode, being a first prototype developed in the university facilities of the final plant. All valves are convertible to electro–valves to facilitate its transformation from manual to automated. Thus, it has two pumps, a manual pump (9) and an electric pump (8). These pumps move water from one container to another or from the water source to the plant (1). The phase of preparing coagulant (2) is the one having higher energy demand as it has a grinder (11) that crushes *M. oleifera* seeds and an agitator (10) mixing it with clean water. Moreover, the automated plant needs an agitator for water processing, where water to treat (1) by effect ventury mixes with the coagulant solution (3) in two phases: a fast and a slow (5) agitation. The thin container (4) is part of the manual design of the plant, which design dimensions offer a natural agitation between 80–100 rpm. This container (4) is the only dispensable part during automation, as both agitation processes can be done in container (5) by adjusting agitator's speed (10). These agitation processes form the flocculants that eliminates turbidity and microorganisms. After treatment, drinkable water is stored (6) and separated from sludge (7).

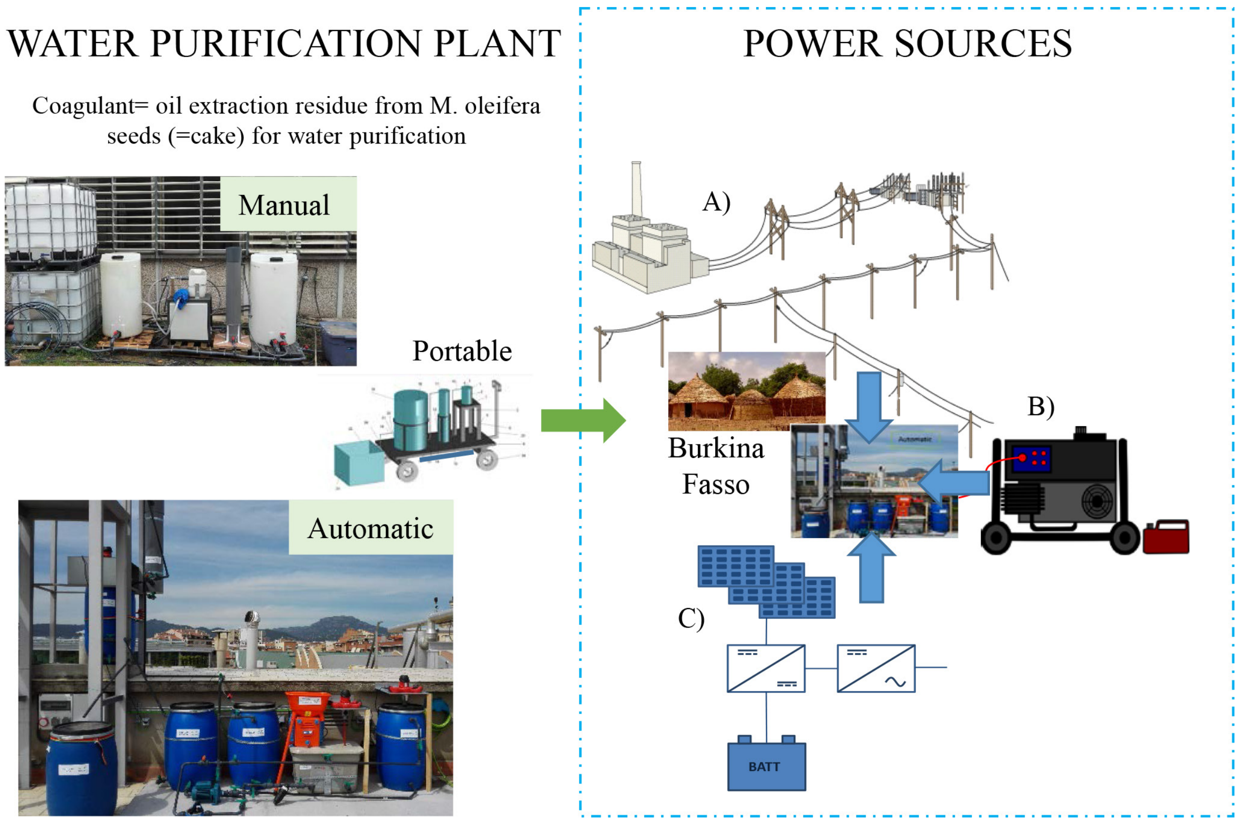


Fig. 1. System analyzed: Manual purification plant (top–left). Automated plant (bottom–left). 3 scenarios (A: electricity grid, B: diesel generator and C: solar panels supported by second life EV batteries) to power up the automated purification plant (right side).


Fig. 2. Automated plant. 1) Water to treat container; 2) Coagulant preparation process; 3) Coagulant container; 4) Fast agitation; 5) Slow agitation; 6) Drinkable water; 7) Sludge; 8) Electric pump; 9) Manual pump; 10) Agitators; 11) Grinder.

For its monitoring, the control system counts on several sensors for pH, turbidity and TOC analyzers among other elements, which allow a constant knowledge of water treatment. This complex system is under use on a preliminary stage in the pilot plant to be able to see the plant's performance before its deployment in Burkina Fasso.

Therefore, automatization incorporates electric and electronic elements that need power supply. Knowing that local government identified that "The most important challenge Burkina Faso faces is to provide meaningful livelihoods to a growing population". Adequate access to affordable energy and water are required [5].

Thus, the main objective of this study is to find the most suitable and sustainable power supply option with regards to the specific zone of the country. This study presents three possible alternatives to power the plant (A: electricity grid, B: diesel generator and C: solar panels supported by second life EV batteries), as Fig. 1 shows. These three alternatives are assessed by means of life cycle assessment (LCA) methodology following the procedures of the ISO 14000 environmental management standards (ISO 14040:2006 [6] and 14044:2006 [7]). LCA is a technique to assess environmental impacts associated with all the stages of a product life from cradle to grave. Comparative LCA studies of renewable energy systems and fossil energy systems are reported in previous literature [8,9] but as far as we know there are no LCA studies focused on the power supply needed to operate a water purification plant located in impoverished countries.

## 2. Experimental

This article discusses the possibility to deploy a sustainable system providing water purification and electricity to a village of Burkina Faso. The case study is located on a rural settlement in Burkina Faso (Western Africa). The project evaluates the impact of different energy power supplies to power up a constructed water purification plant incorporating the above–mentioned natural cake coagulants. This automated plant works for 16 h a day to produce 10,000 L of drinkable water, corresponding to 500 inhabitants considering the minimum 20 L per person per day discussed to be a human right.

The corresponding energy necessary to produce this quantity of purified water per day is 11.178 Wh. As previously mentioned, three scenarios are considered to power up the water purification plant (Fig. 1).

The environmental impact of these three scenarios is done following the life cycle assessment (LCA) methodology based on energy and resources consumption during the material extraction, elements manufacturing, use and dismantle phases. To do so, we took advantage of the Ecoinvent 9 database [10] to compile a comprehensive and comparable inventory. The LCA software used for this analysis was Simapro.

Here below follows a detailed explanation of the boundaries of each scenario or system, counting, in all of them on a 10-year period frame:

Scenario A – Take energy directly from the electricity grid: Although knowing the few electricity infrastructure of the country, we assumed that, for this case, it is not necessary to enlarge the electricity grid, that is, the village has already access to it.

This study case considers the environmental impact to generate and bring electricity to the village. This includes the different voltage transformations (high/medium– medium/low) and the distribution losses of the electricity grid in these different stages. As depicted in Fig. 3, the energy is taken from a low voltage network through a local medium/low voltage transformer that power up the whole village.

The LCA system considers:

- Energy generation from different power sources at plant. 40,278 kWh from an oil generation plant, which represents an 87% of the global electricity generation in Burkina Faso, and 6,232 kWh (13%) coming from hydroelectric generation. The electricity efficiency of these power plants is based on the average efficiency of plants in the Union for the Coordination of the Transmission of Electricity (UCTE) countries.
- Technical and distribution losses that rise up to 14% [11].
- System electricity consumption (40,799 kWh all along this 10 y).

B.– The second alternative is to power up the water purification plant by means of a fuel generator. This case is, by far, the simplest system of all. A basic and affordable diesel generator dimensioned to fill the installation requirements, is used to power it up and make it work as it is shown in Fig. 4. This system considers a generic module to estimate the environmental impact due to the use of diesel. This module includes the diesel consumption necessary to provide 40,799 kWh through 10 years, its emission and infrastructure for the use of diesel in electric generation.

The connection of the power plant is done directly from this generic module to the purification plant. This module includes a AC/AC converter that adapts the output voltage of the generator to the load.

C.– Finally, taking into account that the rainfall season takes three months per year and that they are becoming less predictable and constant [12], photovoltaic panels to power up the plant are the last studied alternative [13].

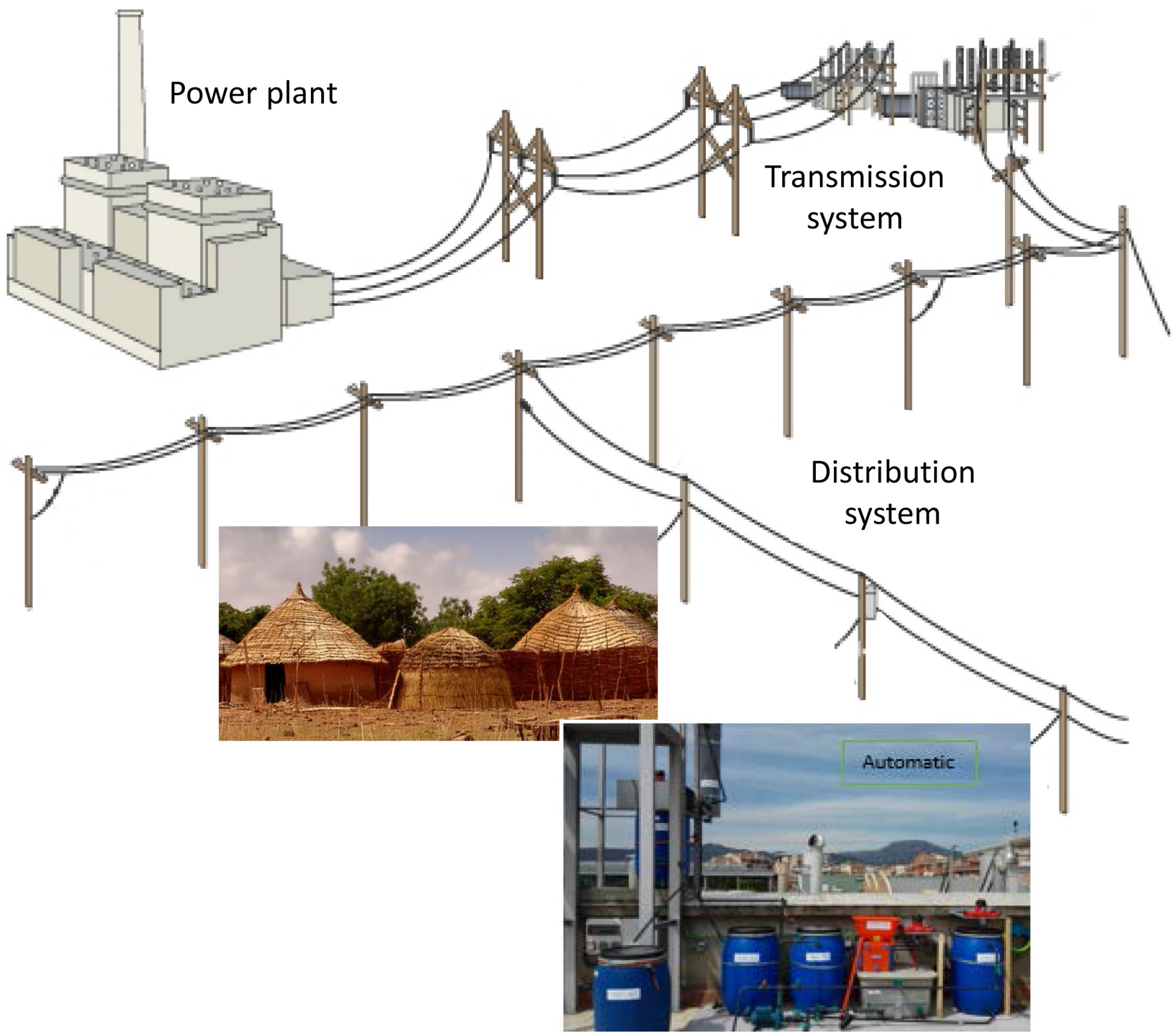


Fig. 3. Schema of the electricity grid system that provides power to the village and purification plant in scenario A.

To ensure reliability and continuous operation, the system incorporates an energy storage system. The innovation of this system consists in the fact that its batteries are reused from electric vehicles (EV). Thus, the system uses 2nd life batteries from EV as energy support to photovoltaic panels. When new, the capacity of these batteries is 24 kWh. However, when they lose a 20% of its capacity due to aging, they are not useful for traction purposes [14]. Nonetheless, they still have an 80% of its initial capacity and they are suitable for stationary applications such as this one following the transformation stages described in previous literature [15]. Moreover, second life battery aging simulations showed that their expected lifetime extends for more than 20 years on stationary applications such as the one presented in this study [16].

For this study case, the electricity is generated by solar panels. As shown in Fig. 5, during day hours, this electricity goes through a DC/DC transformer, which is connected to the battery and to another DC/AC transformer responsible to provide alternating current to the system. More precisely, the system counts on:

- The fabrication (considering material extraction and energy consumption) of a 150 kg $LiFePO_4$ re–used battery coming from already used electric vehicles.
- The fabrication (considering material extraction and energy consumption) of solar panel boards to cover 16 $m^2$.
- The fabrication (considering material extraction and energy consumption) of a 2.5 kW DC/DC transformer

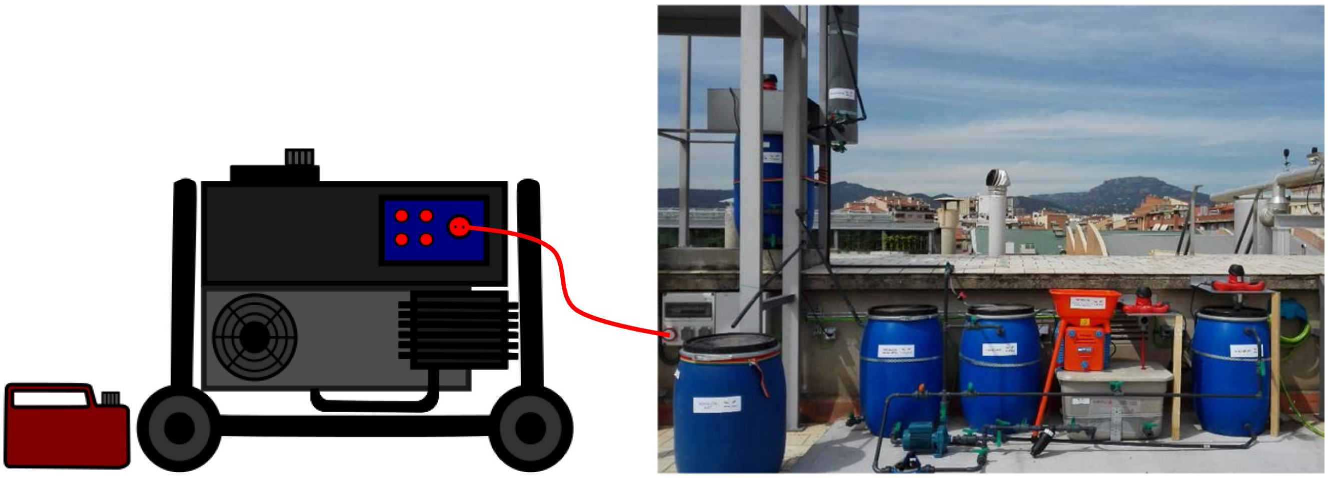

Fig. 4. Schema of the system based on a diesel generator to supply power to the purification plant in scenario B.

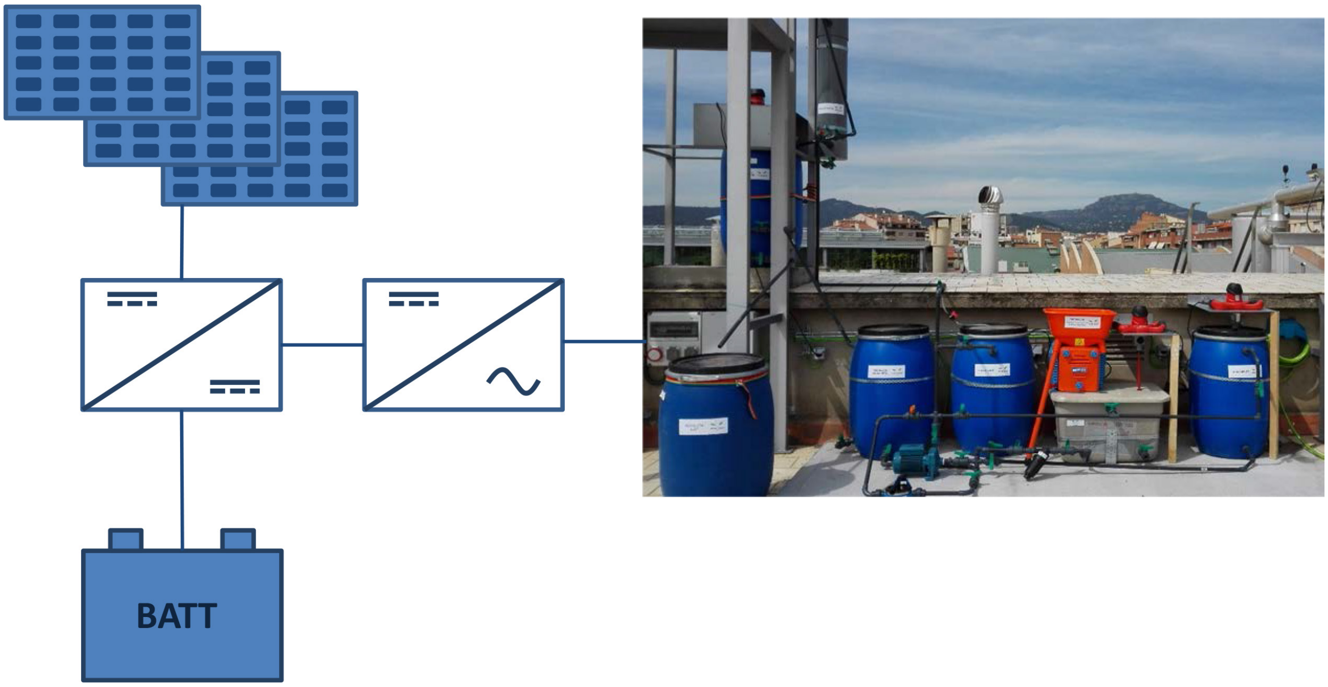


Fig. 5. Schema of the renewable energy system that supplies power to the purification plant in scenario C.

- The fabrication (considering material extraction and energy consumption) of a 2.5 kW AC/DC transformer

The information regarding EV second life batteries, power converters, solar panels, diesel generator and the emissions from energy production from the central energy power plant are included in the Ecoinvent 9 libraries inside Simapro. The methodology used to calculate the environmental impact is the ReCiPe Midpoint (H/A) Worldwide.

All impact categories have different units, summarized in Table 1. However, to present the results in a comprehensive way, the ReCiPe method weights each category so they can be presented under the same axis based on a value expressed in kilo–points.

Finally, an uncertainty analysis of the global impact of each scenario was carried out by means of a Montecarlo simulation available in the same Simapro software.

## 3. Results and discussion

Fig. 6 shows the LCA results for the three scenarios proposed. As we can see, the less pollutant option for this case in Burkina Faso is the "solar panels supported by second life EV batteries". In comparison to the other two scenarios, this system entails a significant reduction of the environmental impact, mainly in the categories of climate change and fossil depletion. In fact, human toxicity (grey section in Fig. 6), caused by silicon of solar panels, is the only category that has higher values with respect to the other two scenarios. Nevertheless, this category has a very small relative impact. Maybe the use of other renewable energy sources would reduce even more this impact, however, sun is widely available in this region of the world.

Moreover, Fig. 6 shows that in all the studied cases there are mainly 5 categories taking most of the environmental impact. These categories are: Fossil depletion (pale blue), Particulate matter formation (darker blue), Climate change human health (medium blue), Climate change ecosystems (cyan blue) and Human toxicity (grey).

Finally, the uncertainty analysis shows that results coming from scenario A are more robust than results in scenario B and C. In fact, the worst results come from scenario B, where the environmental impact may increase by a 58% or reduce 34%. Nonetheless, even on the upper and lower limits, the classification will not change, having the scenario B the highest impact and followed by scenario A. In all cases, the scenario C is the one with lower environmental impact.

Fig. 7 shows the results grouped and normalized in three categories: Human health, Ecosystems and Resources, described in Table 1. We should highlight that the "Diesel generator" scenario has the highest impact on

Table 1
Specification of the impact categories included in the analysis

| Impact category | Acronym |
|---|---|
| Climate change, kg $CO_2$ eq/y | CC |
| Ozone depletion, kg CFC-11 eq/y | OD |
| Terrestrial acidification, kg $SO_2$ eq/y | TA |
| Freshwater eutrophication, kg P eq/y | FE |
| Marine eutrophication, kg N eq/y | MEP |
| Human toxicity, kg 1,4-DB eq/y | HT |
| Photochemical oxidant formation, kg NMVOC/y | POF |
| Particulate matter formation, kg $PM_{10}$ eq/y | PMF |
| Terrestrial ecotoxicity, kg 1,4-DB eq/y | TET |
| Freshwater ecotoxicity, kg 1,4-DB eq/y | FET |
| Marine ecotoxicity, kg 1,4-DB eq/y | MET |
| Ionising radiation, kg U235 eq/y | IR |
| Agricultural land occupation, $m^2a/y$ | ALO |
| Urban land occupation, $m^2a/y$ | ULO |
| Natural land transformation, $m^2/y$ | NLT |
| Water depletion, $m^3/y$ | WPD |
| Metal depletion, kg Fe eq/y | MRD |
| Fossil depletion, kg oil eq/p/y | FRD |
| **Groups** | |
| Ecosystems, species.y/y | |
| Human health, DALY/y | |
| Resources, $/y | |

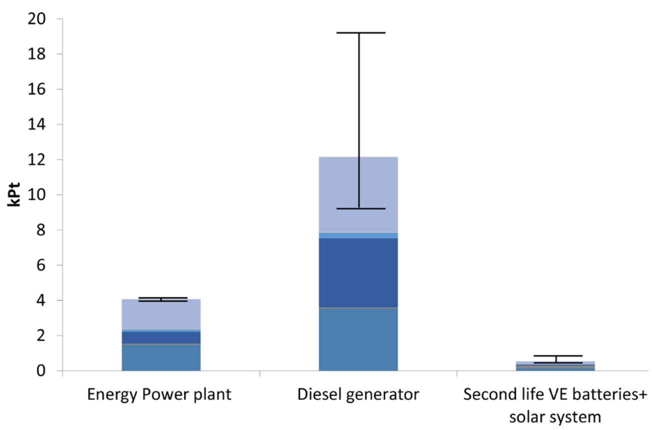


Fig. 6. Results for the three scenarios proposed.

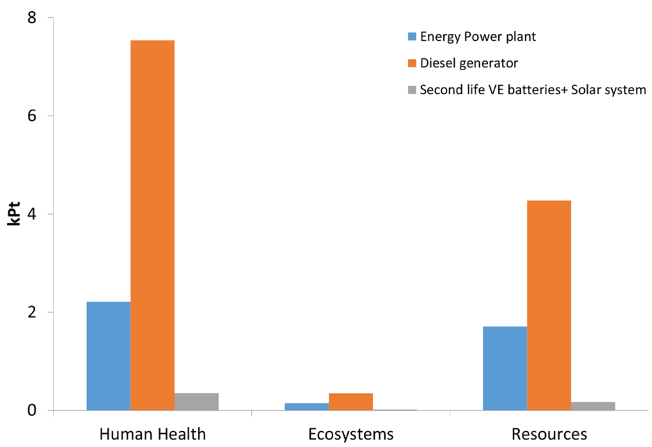


Fig. 7. Results for the three scenarios proposed.

all categories with an enormous difference. Again, the scenario having lower impact is the "solar panels supported by second life EV batteries". Notice that the impact on ecosystems is 0.0157 kPts against the 0.3471 of the "Diesel generator" or the 0.145 "Energy Power plant", corresponding to 22 and almost 10 times lower impact respectively. This relation is followed in the other two grouped categories, where scenario 3 is always the one having, by far, lower impact and the diesel generation case is more aggressive in all cases.

What can be seen from these results is that the environmental impact caused by the manufacture processes to build the solar panels, converters and battery is lower than the impact caused by the consumption of, mainly, fuel or diesel from the electricity generators (either in a power plant or the small generator next to the purification plant) during the 10 year period considered in this analysis.

## 4. Conclusions

A system that prevails along time should be capable of self–reproduction and capable to obtain raw materials for itself. This is the case for the water purification plant presented in this paper.

For one side, the plant purifies and eliminates turbidity on water by means of a natural coagulant/flocculant, which is the residual cake of the oil extraction process from *M. oleifera* seeds, which tree is abundant in the region.

On the other hand, considering the fragile nature of the subject of potable water supply to a settlement in a country like Burkina Faso, it is clear that the use of local energy production for the purification water plant is of paramount importance. To do so, we presented three scenarios to power up the water purification plant, named: "Energy Power plant" (scenario A), "Diesel generator" (scenario B) and "solar panels supported by second life EV batteries" (scenario C). The third scenario is especially relevant because it reuses EV batteries, providing an affordable energy storage system and giving an additional value to this automotive waste, which still has 80% of its initial capacity. Moreover, this system transforms solar energy to electricity with photovoltaic panels.

The analysis of the environmental impact of these three scenarios, knowing that in all three cases there is an investment need to set up the installation that will offer energy, allows us to clearly state that the "solar panels supported by second life EV batteries" scenario is more environmentally friendly than the other two scenarios. Additionally, regarding sustainability, this scenario works without any third party contribution. On the contrary, the other two scenarios need to obtain energy or raw materials from other stakeholders. The "Energy Power plant" scenario demands monthly payments to the energy company to have access to the electricity grid, while the "Diesel generator" needs to buy fuel to distributors to run the generator.

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## References

[1] A.L. Ahmad, S. Sumathi, B.H. Hameed, Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC. Chem. Eng. J., 118 (2006) 99–115.
[2] S.Y. Choy, K.M. Nagendra, T. Yeong, M.E. Raghunandan, R.N. Ramanan, Utilization of plant–based natural coagulants as future alternatives towards sustainable water clarification. J. Environ. Sci., 26 (2014) 2178–2189.
[3] M.H. Bichi, A review of the applications of *Moringa oleifera* seeds extract in water treatment. Civil Environ. Res., 3 (2013) 7610–7615.
[4] B. Amante, V. Lopez, T. Smith, Valuation of oil extraction residue from *Moringa oleifera* seeds for water purification in Burkina Faso, Desal. Water Treat., 57 (2014) 2743–2749.
[5] MMCE (Ministère des Mines des Carrières et de l'Energie). Vision 2020 de l'accès aux services énergétiques modernes au Burkina Faso, 2008, http://www.mepred.eu/_docs/Vision_2020_final.pdf.
[6] ISO 14040 (2006): Environmental management – Life cycle assessment – Principles and framework, International Organisation for Standardisation (ISO), Genève.
[7] ISO 14044 (2006): Environmental management – Life cycle assessment – Requirements and guidelines, International Organisation for Standardisation (ISO), Genève.
[8] V. Kabakian, M.C. McManus, H. Harajli, Attributional life cycle assessment of mounted 1.8 kWp monocrystalline photovoltaic system with batteries and comparison with fossil energy production system, Appl. Energ., 154 (2015) 428–437.
[9] C. Smith, J. Burrows, E. Scheier, A. Young, J. Smith, T. Young, S.H. Gheewala, Comparative life cycle assessment of a Thai Island's diesel/PV/wind hybrid microgrid, Renew. Energ., 80 (2015) 85–100.
[10] Ch. Weidema, R. Bauer, Ch. Hischier, Mutel, J.T. Nemecek, C.O. Reinhard, B.P. Vadenbo, G. Wernet, The ecoinvent database: Overview and methodology, Data quality guideline for the ecoinvent database version 3, www.ecoinvent.org (2013).
[11] African Development Fund. Project: Electricity Infrastructure Strengthening and Rural Electrification Project. (2014).
[12] http://sdwebx.worldbank.org/climateportal/index.cfm last accessed: 06/06/2016
[13] H.M. Toonen, Adapting to an innovation: Solar Cooking in the urban households of Ouagadougou (Burkina Faso), Phys. Chem. Earth, 34 (2009) 65–71.
[14] G.L. Gillian, T. Jiang, P. Ghanim, R. Kotter, The effect of cycling on the state of health of the electric vehicle battery, 48th International Universities' Power Engineering Conference (UPEC) (2013).
[15] L. Canals–Casals, B. Amante–García, Assessing electric vehicles battery second life remanufacture and management, J. Green Eng., 2016, DOI: 10.13052/jge1904–4720.614.
[16] L. Canals–Casals, B. Amante–García, F. Aguesse, A. Iturrondobeitia; Second life of electric vehicle batteries: relation between materials degradation and environmental impact, Int. J. Life Cycle Assess., DOI 10.1007/s11367–015–0918–3, (2015).