AGRITECH

National Research Centre for Agricultural Technologies

BOtanical REsources for ALternative battEries -

"BO.RE.AL.E."

AMBITO: NUOVE MOLECULE, PRODOTTI E PROCESSI AD ALTRO VALORE AGGIUNTO PER LA VALORIZZAZIONE DI RIFIUTI, SCARTI, SOTTOPRODOTTI E COPRODOTTI AGRICOLI O PER L'AGRICOLTURA

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2. EXECUTIVE SUMMARY

This report presents an analysis of the production process of carbon dots (CDs) derived from *Laurus nobilis* leaves, as well as the preparation phase of the slurry in which they were used. The synthesis of CDs remains the most energy-intensive phase, mainly due to the laboratory-scale nature of the process. Future optimization efforts should focus on this step to further reduce environmental impact and enhance process sustainability.

Separately, during the slurry preparation phase, several technological options were tested, although not all of them were adopted in the final process. This section presents the main alternatives considered, focusing on the technical and environmental reasons that led to their exclusion.

While these options are not included in the full LCA study, their evaluation helped to strengthen the robustness of the final decision.

3. INTRODUCTION

Although the LCA results confirmed the environmental benefits of the developed process, they also highlighted some areas that could be improved. One of the most critical aspects is the energy consumption during the synthesis of carbon dots. This is mainly since the process is still performed at laboratory scale, where efficiency is lower compared to industrial-scale production. In industrial settings, energy use is typically optimized thanks to larger production volumes and more efficient equipment.

This report presents possible alternatives to improve the synthesis process of CDs, aiming to reduce its overall environmental impact. In addition to the synthesis phase, special attention was given to the preparation of the slurry, which is also a key step for both the performance and the environmental footprint of the final product.

During the experimental phase, different process configurations for slurry production were tested. These included variations in the ratio of reagents and the mixing technologies used. Each alternative was evaluated from an environmental perspective to select the most sustainable option. The final choice was the formulation that showed the best balance between functional performance and low environmental impact. The reasons behind this decision are explained in the following sections, with a focus on identifying the most critical inputs and the main sources of environmental impact in each process.

This approach helped not only to define an optimized production route, but also to identify priorities for future improvements, such as replacing high-impact solvents or reducing energy consumption by upgrading lab-scale technologies.

4. METHODOLOGY

4.1 Carbon-Dots Synthesis

As shown in **Figure 1**, electricity is the main contributor to environmental impact across all categories considered, except for water use. This is mainly because the bay leaves used in the process come from essential oil extraction and are considered to have zero impact, and the amount of water used is minimal. Therefore, the environmental burden is mostly associated with electricity consumption.

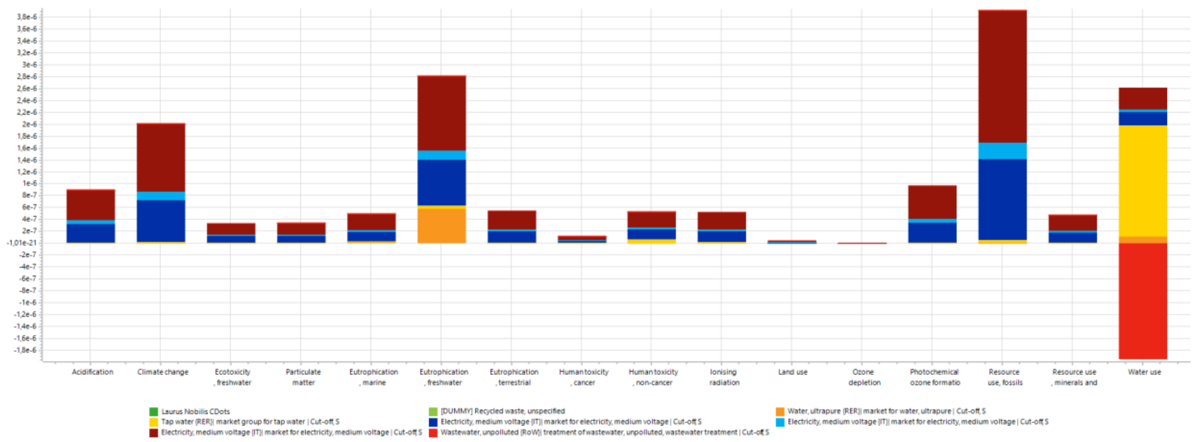

Figure 1: *impact assessment (normalized) for the production of 200 mg of CDs from bay leaves.*

To reduce energy use, one potential improvement could be eliminating the oven-drying step and testing whether similar results can be achieved at room temperature under controlled conditions.
A comparison between the current process and an alternative scenario that excludes the use of the oven, in **Figure 2**, shows that the overall environmental impacts could be reduced by about half, significantly improving sustainability performance.

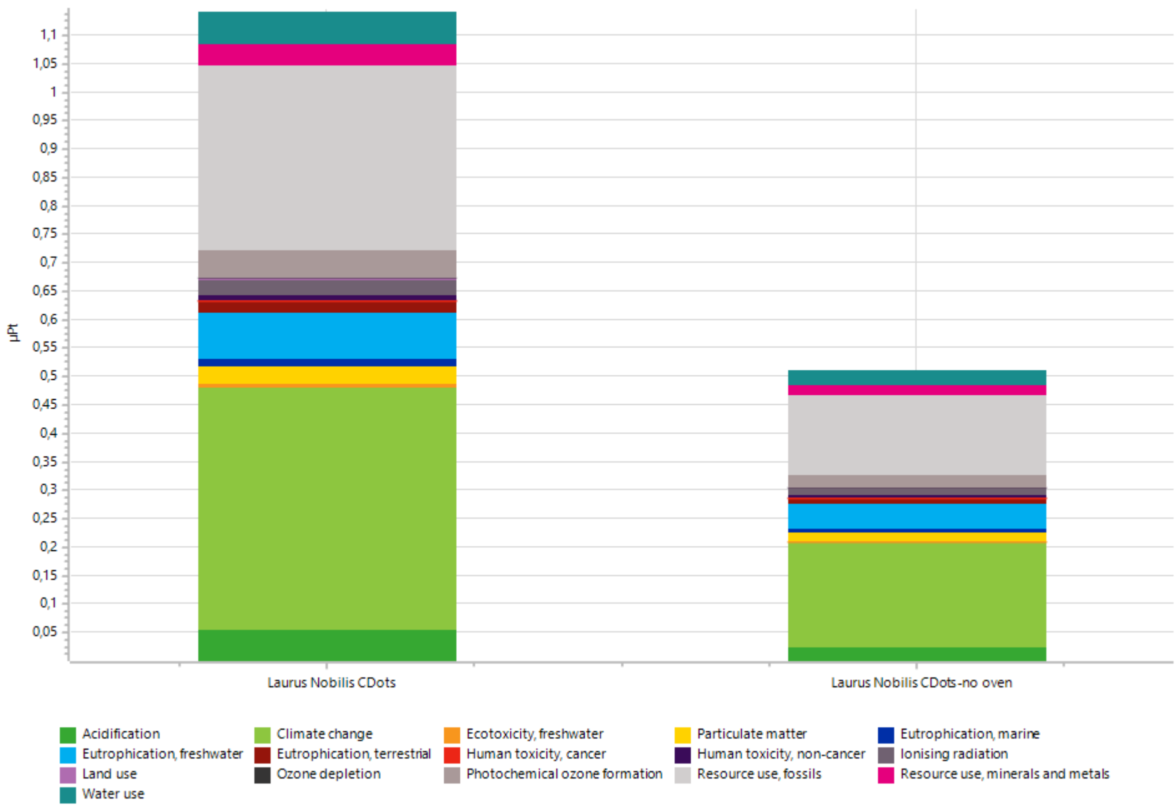

***Figure 2**: comparison between the current process and an alternative scenario that excludes the use of the oven, for the sixteen impact categories.*

Moreover, the current analysis assumes electricity from the national grid mix. However, if the production lab were powered by renewable energy sources, such as a photovoltaic system, the impact from electricity consumption could be further and significantly reduced.

4.2 Slurry preparation

During the slurry preparation phase, two formulations with different proportions of reagents were tested. The one with the best performance was selected. However, an environmental comparison was also carried out to assess which option was more sustainable, to make an informed choice that considers both technical and environmental aspects.
Once the best slurry was selected, it became clear that the mixing phase, involving magnetic stirring and ultrasonic bath, required long processing times and energy consumption. To reduce this, an alternative method using the Ultra-Turrax T10 for 15 minutes was tested.

To support the final choice of the optimized production method, the main alternative scenarios tested during the experimental phase were modeled in SimaPro. These results do not represent a full LCA, but rather a comparative analysis based on consistent data with the official study.

5. RESULTS AND DISCUSSION

5.1 Carbon-Dots Synthesis

Although the comparison between the Carbon Dots produced in this project and commercial alternatives such as carbon black does not currently favor those derived from bay leaves, these results should not be interpreted as an indication of the process unsustainability. In fact, the environmental impacts largely reflect the operating conditions of a system still confined to the laboratory scale.
Despite the use of normalization criteria to mitigate this limitation, it is reasonable to assume that scaling up the process, first to a pilot scale and then to industrial production, could lead to significant improvements in energy efficiency, resulting in a considerable reduction of the associated environmental impacts.

5.2 Slurry preparation

The two slurries were compared based on the quantities produced: 54.6 mg for slurry A and 56.4 mg for slurry B. The unit used for comparison was the Pt (person equivalent), which reflects the average yearly environmental impact of a person at global level. The results in **Figure 3** show that slurry B has a significantly lower environmental impact.

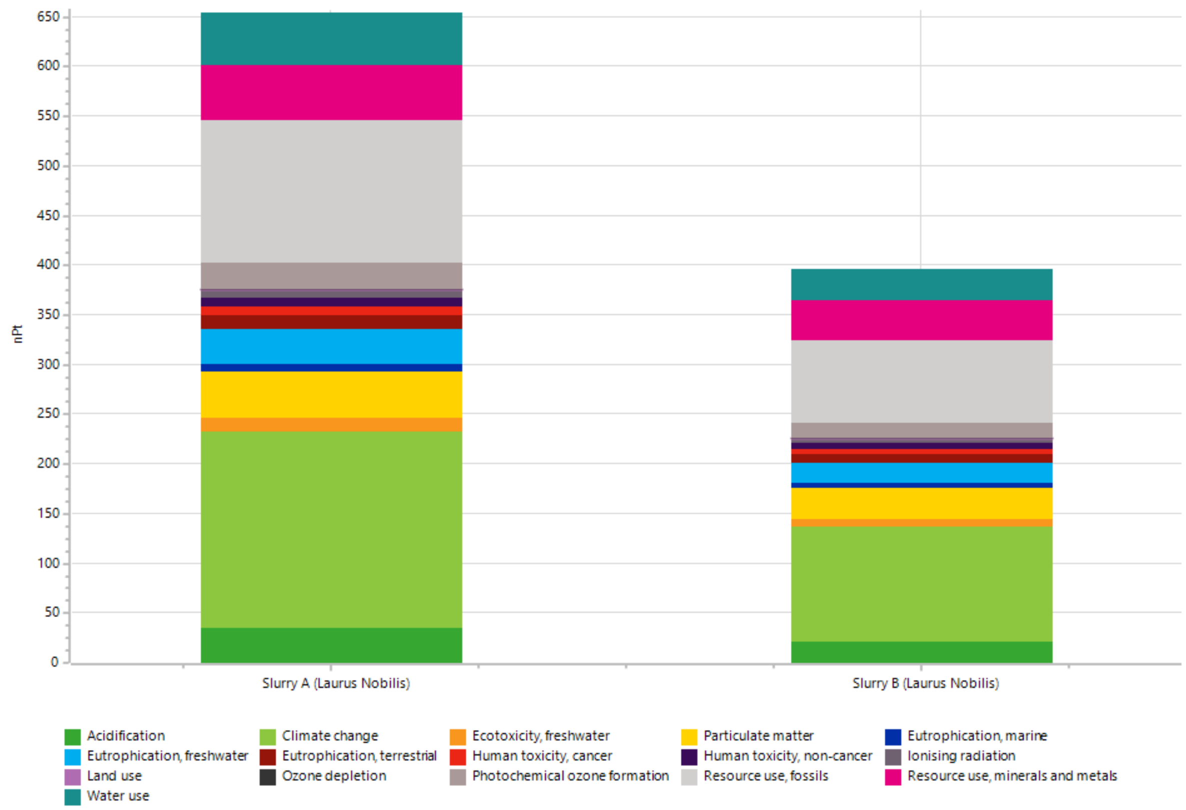

***Figure 3**: comparison between Slurry A and Slurry B, for the sixteen impact categories.*

A detailed analysis of each impact category, in Table 1, shows substantial differences across almost all indicators.

Select	Damage category	Unit	Slurry A (Laurus	Slurry B (Laurus
☑	Total	nPt	655	397
☑	Acidification	nPt	35	21,8
☑	Climate change	nPt	198	115
☑	Ecotoxicity, freshwater	nPt	13,2	8,27
☑	Particulate matter	nPt	46,9	30,8
☑	Eutrophication, marine	nPt	7,84	4,66
☑	Eutrophication, freshwater	nPt	35,6	21,1
☑	Eutrophication, terrestrial	nPt	13,2	7,88
☑	Human toxicity, cancer	nPt	8,91	5,87
☑	Human toxicity, non-cancer	nPt	8,5	5,44
☑	Ionising radiation	nPt	7,77	4,18
☑	Land use	nPt	1,83	1,07
☑	Ozone depletion	nPt	0,172	0,0963
☑	Photochemical ozone formation	nPt	25,5	15,2
☑	Resource use, fossils	nPt	144	83,1
☑	Resource use, minerals and metals	nPt	54,5	40,6
☑	Water use	nPt	53,4	31,7

***Table 1**: comparison of the nPt values of each impact category for Slurry A and Slurry B.*

Table 2 breaks down the total impact by input, helping to identify which parts of the production process contribute most to the overall impact.

No	Process	Project	Unit	Slurry A (Laurus	Slurry B (Laurus
	Total of all processes		nPt	655	397
	Remaining processes		nPt	0	0
1	Slurry A (Laurus Nobilis)	C-Dots	nPt	8	x
2	Slurry B (Laurus Nobilis)	C-Dots	nPt	x	4,8
3	Anthraquinone {GLO}| market for anthraqu...	Ecoinvent 3 - alloca...	nPt	74,1	74,1
4	Carbon black {GLO}| market for carbon bla...	Ecoinvent 3 - alloca...	nPt	x	2,92
5	Electricity, medium voltage {IT}| market fo...	Ecoinvent 3 - alloca...	nPt	172	72,4
6	N-methyl-2-pyrrolidone {GLO}| market for...	Ecoinvent 3 - alloca...	nPt	389	233
7	Polyvinylfluoride {GLO}| market for polyvin...	Ecoinvent 3 - alloca...	nPt	6,55	6,79
8	Tap water {RER}| market group for tap wat...	Ecoinvent 3 - alloca...	nPt	19,4	10,2
9	Wastewater, unpolluted {RoW}| treatment ...	Ecoinvent 3 - alloca...	nPt	-17,8	-9,38
10	Water, ultrapure {RER}| market for water, u...	Ecoinvent 3 - alloca...	nPt	3,4	1,79

***Table 2**: comparison of the nPt values for each input for Slurry A and Slurry B.*

The largest contributor is N-methyl-2-pyrrolidone (NMP): 0.5 mL was used in slurry A and 0.3 mL in slurry B, which is nearly a 50% reduction. The second most important contributor is electricity consumption, mainly related to the synthesis of carbon dots (CDs). Since this process was carried out at lab scale, it involves high energy intensity. The difference in energy use between the two slurries is due to the amount of CDs used: in slurry B, it's about half that of slurry A.

The reagent mixing steps also contributed differently. In slurry A, magnetic stirring lasted 4 hours, while only 40 minutes were needed for slurry B. Similarly, ultrasonic bath time was 25 minutes for slurry A and 8 minutes for slurry B.

Another relevant contributor is anthraquinone, used in equal amounts in both slurries, thus having the same environmental impact in both cases.

These results confirm that slurry B is the more environmentally preferable option. Following this choice, as shown in **Figure 4**, the use of the Ultra-Turrax T10 was tested to replace magnetic stirring and ultrasonic bath, aiming to further reduce energy use.

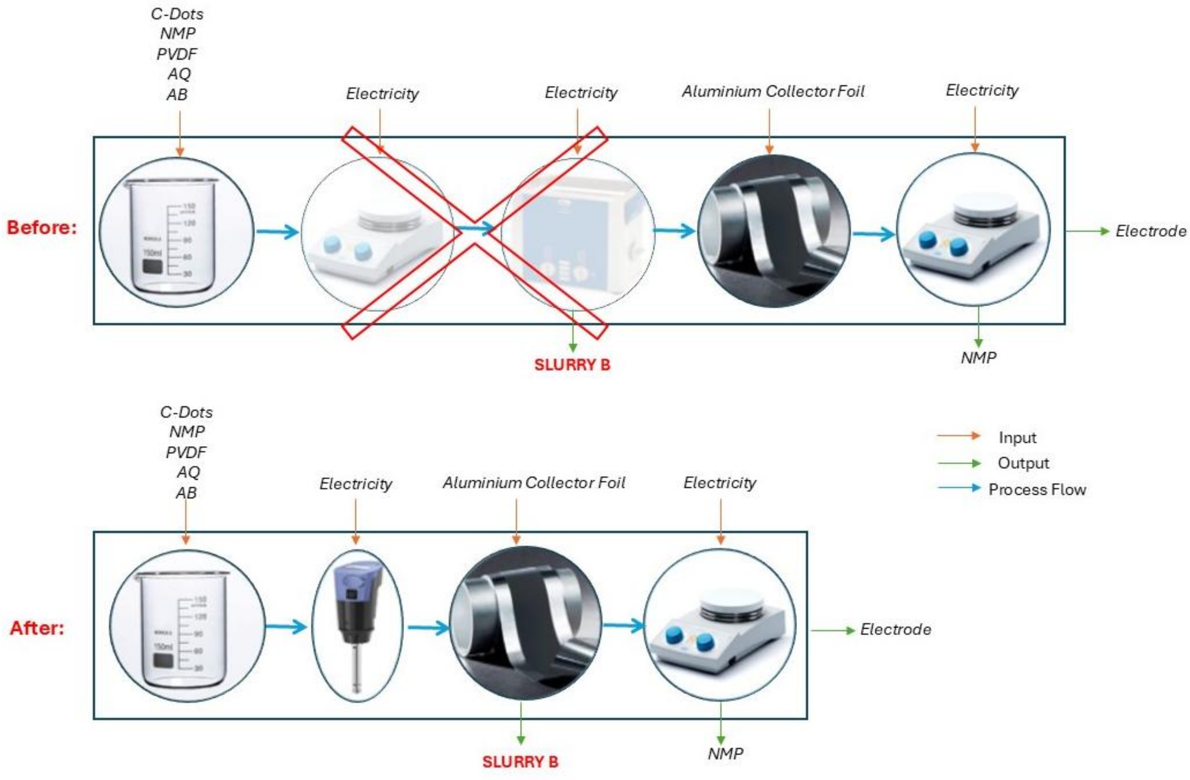

***Figure 4**: replacing mechanical stirring with Ultra-Turrax stirring.*

Although the new method reduces processing time, the comparison across impact categories in **Figure 5** showed no major environmental benefit, since the energy used during mixing contributes only marginally to the overall environmental impact.

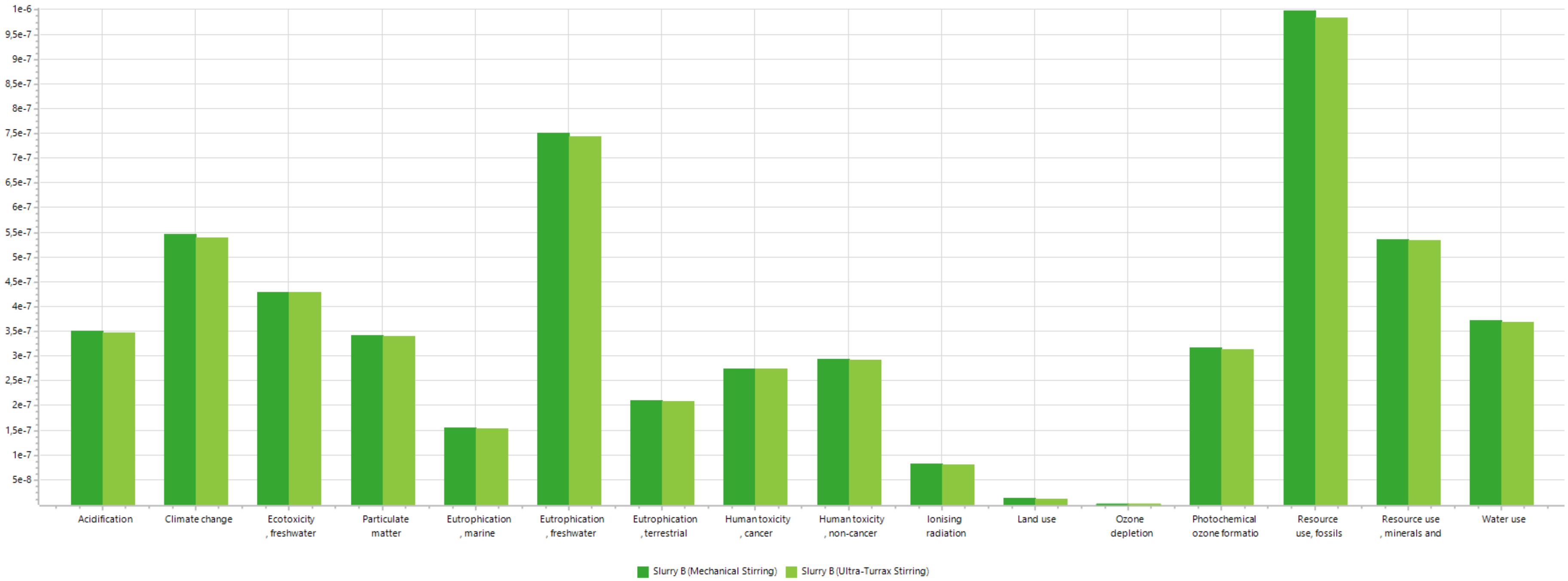

***Figure 5**: comparison between mechanical stirring and Ultra-Turrax stirring for each of the 16 impact categories.*

As shown in **Figure 6**, NMP remains the main contributor, followed by anthraquinone and CDs, while the impact of energy consumption is minimal.

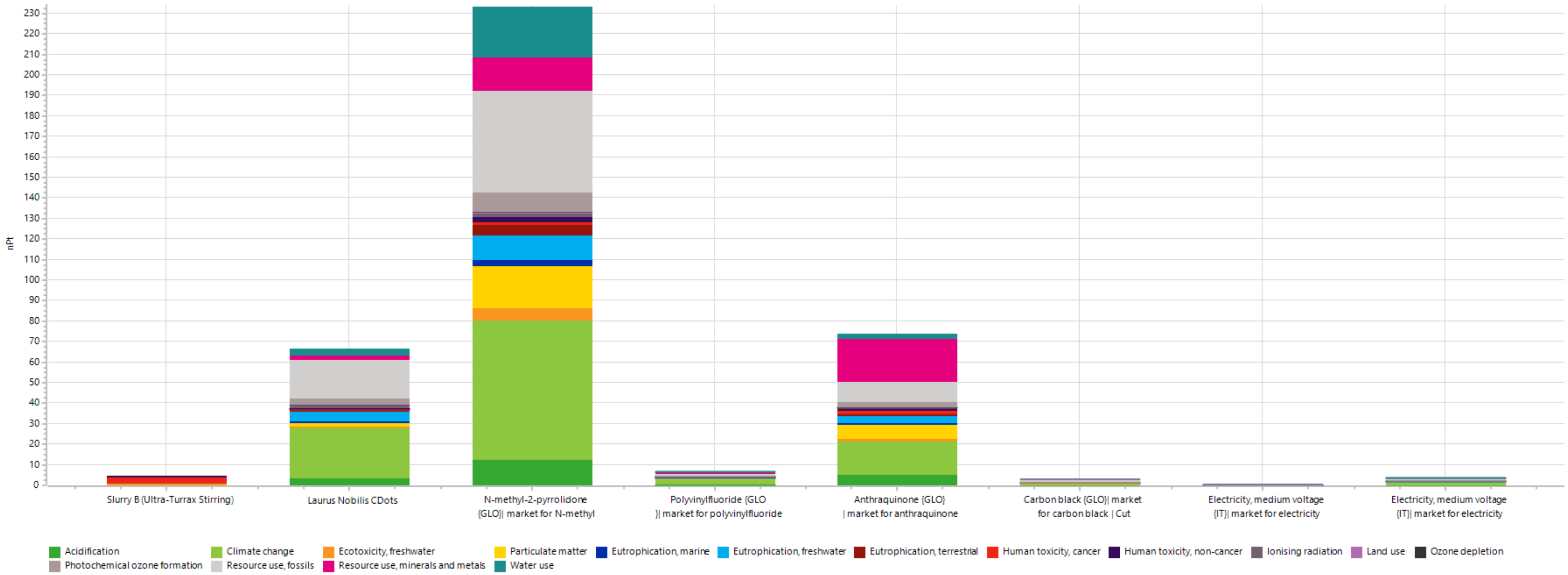

***Figure 6**: overall environmental impact of each process input.*

6. CONCLUSIONS

6.1 CDs synthesis

At this stage, the process is still limited to laboratory scale, which inevitably leads to higher energy consumption and less efficient use of resources compared to industrial settings. As such, direct comparisons with market-ready products, such as conventional cathode materials or carbon-based additives, may be premature and potentially misleading.

Scaling up the production process, optimizing operational parameters, and integrating renewable energy sources could significantly reduce environmental impacts, particularly those related to electricity consumption, which currently represents the most relevant contribution across most impact categories.

6.2 Slurry Preparation

During the slurry preparation phase, different alternatives were tested, both in terms of reagent proportions and equipment used, to develop a functional product with the lowest possible environmental impact. Slurry B was found to be the best option, and its energy consumption was further reduced by replacing magnetic stirring and ultrasonic bath with the Ultra-Turrax T10.

However, the results showed that the energy-related impacts are minor compared to those caused using NMP as a solvent and anthraquinone. Future research should focus on these components to improve the overall environmental performance of the process.