Evaluation of the environment impact of extraction of bioactive compounds from *Dacryodes rostrata* using Deep Eutectic Solvent (DES) using Life Cycle Assessment (LCA)

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**Abstract.** Polyphenols, the most abundant and naturally occurring antioxidants, was found to be the highest in *Dacryodes rostrata* seed as compared to the peel and pulp of the fruit. Growing technologies in the past decades have led to the interest of reviewing and developing environmental-friendly green extraction solvent, as the commonly used conventional solvent imposing various risks to human health and environment. An environmental-friendly extraction technique was established using deep eutectic solvent (DES) as the alternative extraction solvent has been considered. The main objective of this study was to analyse the environmental impact and performance of laboratory processes for phenolic compounds extraction from *D. rostrata* peel using different solvent, by means of life cycle assessment (LCA). A comparative analysis was carried out to evaluate the environmental impacts caused by both solvents, DES and conventional organic solvent, ethanol. The functional unit (FU) was defined as 104.6 mg of extracted polyphenols, measured as gallic acid equivalents (mg GAE)/g dw of *D. rostrata* seed used. The variation of environmental impacts between DES and ethanol as a function of optimum process conditions (temperature, time, solid/liquid ratio, and water addition) was evaluated. According to the environmental profile analyzed, the well-developed ethanol exerted lower impact and energy consumptions as compared to the environmental-friendly green solvent, DES. Besides, transport activities and electricity consumptions from the extraction process was identified contributing highest environment impact.

**Keywords:** *Dacryodes rostrata*; deep eutectic solvent (DES); ethanol; life cycle assessment; phenolic compounds, solid-liquid extraction

1. **Introduction**
Plant phenolics, abundant in the plant kingdom have attracted tremendous interest for their potent antioxidant properties and credibility in the prevention of oxidative stress related diseases like cardiovascular, neurodegenerative and cancer [1]. Vast diversity of indigenous fruits still reported to be underutilized despite being rich in bioactive compounds with a commercial potential of antioxidants due to the lack of information on the recovery of bioactive compounds and the function of antioxidants [2].

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The identification and extraction of phenolic compounds from various plants has thus become a significant field of medical and health study in past few years. *D. rostrata* is an underutilized indigenous fruit that is rich in total flavonoid content (TFC), total phenolic content (TPC), total anthocyanin content (TAC) with significant nutritional content [3]. From previous research works [2–4], it was proven that TPC of the seed extract of *D. rostrata* fruit is higher as compared to the peel and the pulp extract hence, the seed was chosen as the plant material for this present study.

Advanced and growing technology has led to growing interest of reviewing different extraction techniques, as there is no any universal extraction technique that can be applied for all plant phenolics [5]. Despite the extensive studies on the green technologies, conventional solid-liquid extraction (SLE) method is still preferred due to its simplicity, broad applicability in pharmaceutical, chemical and food industries as well as ease in operation [6,7]. To date, the commonly used conventional extraction solvent for SLE technique is methanol and ethanol. However, ethanol is favored due to the low in toxicity as compared to methanol, despite its excellence of extraction efficiency [8]. Also, growing awareness on the environmental impacts due to the large amount of chemical waste generated in industries during the extraction and purification increases the area of study in developing new, more environmental-friendly solvents [9].

In recent years, neoteric solvents consist of ionic liquids (ILs), supercritical carbon dioxide (*scCO₂*), liquid polymers (LPs), deep eutectic solvent (DES), switchable solvents and gas-expanded solvents (GXLs) were being explored. Among them, the most promising alternative green solvent to the conventional solvent is DES [9,10]. It was reported that DES belongs to a class of ILs but is much cheaper compared to the conventional ILs [11]. It is generally a complexion based on readily available and cheap components of quaternary ammonium salts as the hydrogen bond acceptor (e.g., choline chloride) and a hydrogen bond donor (e.g., amines, alcohols, carboxylic acids, sugars, and vitamins [5,12]. In recent studies, DES was reported to have unique physicochemical properties, lower toxicity, bio-degradable and attractive price [13]. Thus, there is growing interest on application of DES for both industry and research as solvents in metal electrodeposition, transformation of cellulose and starch, biomedical applications, separation processes and extraction of bioactive compounds from various plant sources [5,10,14,15]. Although, DES constituents composed of naturally occurring compounds and biodegradable with high safety profile, not much comprehensive study conducted on the extraction of bioactive compounds via SLE method using DES as the extraction solvent. Nevertheless, there is still controversy on the real potential of DES as environmental-friendly green solvent [16]. There, there’s a need to evaluate the environmental impact of using DES as the extraction solvent for bioactive compounds from natural resources.

These days, the major challenge in developing sustainable process is to include environmental consideration in a process design besides economic and productivity consideration [17]. Life cycle assessment (LCA) is a well-recognized tool to evaluate and quantify the environmental performance of a process or product over its life cycle [18]. The environmental impacts of phenolic compound extraction using DES as the extraction solvent via SLE technique remain poorly studied till date. DESs are mostly used in green technologies as the extraction solvent to extract bioactive compounds from various plant materials. However, the application of DES using conventional SLE technique in extracting the phenolic compound from *D. rostrata* seed is still novel. Hence, the major limitation for the analysis is the lack of information on the green extraction solvent that is to be compared with conventional ethanol. For instance, there is no any data available on the TPC of extract can be produced from fruit seed using DES as the extraction solvent via SLE. For the comparative LCA analysis between DES and conventional solvent ethanol, two different peer-reviewed studies were identified addressing to some extent to present study. In a study [19], conducted on *D. rostrata* seed itself to recover bioactive compounds via SLE using ethanol as the extraction solvent. In the study, it is reported that 104.60 mg GAE/g dw of TPC was produced under optimum process conditions of 1:100 g/mL of solid/liquid ratio, 50% ethanol concentration, 303.15 K and 30 minutes of extraction time. Besides, in the study it also concludes that extraction time and temperature have no significant effect on the TPC. In another study [20], a study was conducted on orange peel to extract polyphenolic compounds via SLE using DES as the extraction
solvent. These authors reported that choline chloride-based DES with ethylene glycol as the hydrogen bond donor (HBD) in the ratio of 1:4 outperformed the benchmark solvent, ethanol under optimum process conditions of 333.15 K, 10% of water addition, 100 minutes of extraction time and 1:10 g/mL solid/liquid ratio to provide the highest TPC of extract (3.61 mg GAE/g OP). However, this published literature [20] do not focus on the seed of fruit but when it is compared to other studies this is the closest study to the present work that is conducted on *D. rostrata* seed. Therefore, the data from both aforementioned peer-reviewed studies will be used in the present study to perform the comparative LCA analysis between DES and ethanol as the extraction solvent. Also, the life cycle inventories (LCI) used in this study was primarily based on literatures and secondary data sources instead of primary experimental data.

Based on the aforementioned, present study was aimed to evaluate the potential environmental impacts of both ethanol and DES as the extraction solvent for SLE method to extract phenolic compounds from *D. rostrata* seed under optimum process conditions using a recognized approach in order to determine the best extraction solvent from the point of environmental view. The objective of producing 104.6 mg GAE/g TPC of extract as the functional unit (FU) was fixed. This was accomplished by applying the optimum process conditions of temperature, solid/liquid ratio and water addition during the extraction process. In this study, the variation of environmental profiles was evaluated as a function of optimum process conditions in terms of acidification, global warming air, ecotoxity, eutrophication, human health particulate air, human toxicity, ozone depletion air, fossil fuel use and smog air.

2. Materials and methods

2.1. Life cycle Assessment (LCA) methodology

The software package GaBi (Sphere Solutions GmbH, Germany) was used in this study to build the inventory as well as undertaking the analysis on impact assessment. The principles and framework established for LCA by environmental management standard of ISO 14040:2006 and ISO 14044:2006 includes four main phases that begins with goal and scope definition, followed by life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.

2.1.1. Goal and scope definition. The goal of present study was to compare the potential environmental impacts of a lab scale SLE technique using two different extraction solvents, which are ethanol (96%) as the conventional solvent and DES as the green solvent, to extract phenolic compounds from *D. rostrata* seed under optimum process condition

2.1.2. Functional Unit. The functional unit (FU) of this study was defined based on the objective to extract phenolic compounds from *D. rostrata* seed using DES and ethanol. Hence, the FU adopted for both cases using DES and ethanol was defined as 104.6 mg GAE/g seed of TPC produced. This is because; the data taken from [15, 16], reported that for 1 g of sample used for extraction produced 104.6 mg GAE/g sample of TPC whereas for DES the study conducted on orange peel reported that for 0.5 g of sample used for extraction produced 3.61 mg GAE/g sample of TPC. Therefore, 104.6 mg GAE/g sample of TPC produced was selected as the FU as the study was conducted on the *D. rostrata* seed itself.

2.1.3. Assumptions and Limitations. The LCA approach was subjected to some assumptions and limitations and therefore the results would vary as the assumption made changes. It was assumed that all the chemicals for the extraction process were assumed to travel a distance of 100 km from the wholesaler to the laboratory. *D. rostrata* fruits required for the research were assumed to travel by air with an approximate distance of 980km from wholesaler in Sarawak, Malaysia to the laboratory in
Subang, Malaysia. Besides, no wastewater treatment plant was considered for this study and the waste extract was assumed to be carried with remaining supernatant as emission to freshwater.

2.1.4. **System boundaries.** Fig. 1 and Fig. 2 shows the processes within the system boundaries of both cases using DES and ethanol for this present study. The system includes transportation of raw materials, sample preparation, freeze-drying, grinding, sieving, extraction, centrifugation, evaporation, and disposal. The dataset considered for the system boundaries is cradle-to-grave.
Figure 1 System boundaries for the case using DES as the extraction solvent
Figure 2 System boundaries for the case using ethanol as the extraction solvent
2.1.5. Life cycle inventory. The most laborious procedure in implementing LCA studies is the inventory data collection to create the life cycle inventory (LCI). For a reliable evaluation, it is important to use appropriate and accurate data. The major limitation for LCA analysis in this present study is the insufficient data on the green extraction solvent. Hence, the data was collected from various sources and procedure, which includes generic data, research reports and literatures and reliable online sources. The generic data was taken from Ecoinvent databases that are included in GaBi software. The key inventory of each process along with data sources is as summarized in Table 2 and the detailed explanation for each of the process are given in the following sub-sections.

Transportation
The raw *D. rostrata* fruits were transported via airmail with an approximate distance of 980 km from the Agricultural Research Centre, Department of Agriculture, Sarawak, Malaysia. The chemicals required for the extraction are choline chloride, ethylene glycol and ethanol and were purchased from Sigma-Aldrich, Malaysia. The chemicals were transported on road by a truck for an approximate distance of 100 km from the supplier to the plant site [21]. These assumptions were made to incorporate the emissions of transportation in the present study.

Materials
The quantities of water and chemicals varied based on the extraction solvent used. The masses considered for both cases in LCA are as tabulated in Table 2. The amount of seed sample used for the case using ethanol was taken from a previous study conducted on *D. rostrata* seed to produce 104.6 mg GAE/mg sample of TPC requires 1 g of sample seed [19]. However, for the case using DES as the extraction solvent, the amount of seed sample required were calculated based on the previous study conducted on orange peel where 0.5 g of orange peel able to produce 3.61 mg GAE/g sample of TPC [20]. Hence, based on the FU, to produce 104.6 mg GAE/mg sample of TPC using DES requires 14.49 g of seed sample.

**Table 1** Key inventory analysis of both DES and ethanol

| Material                  | Case 1: Extraction using DES | Case 2: Extraction using ethanol | Unit |
|---------------------------|-----------------------------|---------------------------------|------|
| **Transportation of fruit** |                             |                                 |      |
| Input                     |                             |                                 |      |
| Distance (by air)         | 980                         | 980                             | km   |
| Kerosene                  | 0.26                        | 0.26                            | kg   |
| *D. rostrata* fruit       | 41.6                        | 10.4                            | g    |
| **Output**                |                             |                                 |      |
| *D. rostrata* fruit       | 41.6                        | 10.4                            | g    |
| **Transportation of chemical** |                          |                                 |      |
| Input                     |                             |                                 |      |
| Distance (on road)        | 100                         | 100                             | km   |
| Diesel                    | 0.00218                     | 0.00218                         | kg   |
| Chemical                  | ChCl=28.69 & EG=115.8       | 41.093                          | g    |
| **Output**                |                             |                                 |      |
| Chemical                  | ChCl=28.69 & EG=115.8       | 41.093                          | g    |
| **Storage of fruit seed** |                             |                                 |      |
| Input                     |                             |                                 |      |
| *D. rostrata* seed        | 22.48                       | 5.62                            | g    |
| Electricity               | 4.7                         | 4.7                             | kWh  |
| Output | 22.48 | 5.62 | kWh |
| --- | --- | --- | --- |
| Freeze-drying |  |  |  |
| Input |  |  |  |
| D. rostrata seed | 18.82 | 1.299 | g |
| Electricity | 38.4 | 38.4 | kWh |
| Output |  |  |  |
| Water loss | 4.33 | 0.299 | g |
| D. rostrata seed | 14.49 | 1 | g |
| Seed disposal (landfill) | 3.66 | 4.321 | g |
| DES preparation |  |  |  |
| Input |  |  |  |
| Choline chloride | 28.69 | - | g |
| Ethylene glycol | 115.8 | - | g |
| Electricity: heating | 0.36 | - | kWh |
| : mixing | 0.02 | - | kWh |
| Output |  |  |  |
| DES mixture | 144.49 | - | g |
| Dilution of ethanol |  |  |  |
| Input |  |  |  |
| Ethanol | - | 41.093 | g |
| Water | - | 47.917 | g |
| Output |  |  |  |
| Diluted ethanol | - | 89.01 | g |
| Solid-liquid extraction |  |  |  |
| Input |  |  |  |
| Seed powder | 14.49 | 1 | g |
| Chemical | 144.49 | 89.01 | g |
| Electricity: Heater | 0.833 | 0.25 | kWh |
| : Motor | 0.025 | 0.0075 | kWh |
| Output |  |  |  |
| Extraction mixture [organics] | 173.47 | 90.01 | g |
| Centrifugation |  |  |  |
| Input |  |  |  |
| Extraction mixture [organics] | 173.47 | 90.01 | g |
| Electricity | 0.02 | 0.02 | kWh |
| Output |  |  |  |
| Total phenolic content [organics] | 104.6 | 104.6 | mg GAE/g |
| Wastewater [Emission to fresh water] | 173.47 | 90.01 | g |
| Rotary Evaporator I |  |  |  |
| Input |  |  |  |
| Total phenolic content [organics] | 104.6 | 104.6 | mg GAE/g |
| Wastewater [Emission to fresh water] | 173.47 | 90.01 | g |
| Electricity | 1.7 | 1.7 | kWh |
| Output |  |  |  |
| Water vapour [Inorganic emission to air] | 14.49 | 47.917 | g |
| Total phenolic content [organics] | 104.6 | 104.6 | mg GAE/g |
| Solid waste [Waste for disposal] | 14.49 | 1 | g |
| Ethanol/DES [hydrocarbon emission] | 144.49 | 41.093 | g |
Rotary Evaporator II

| Input | Total phenolic content [organics] | 104.6 | 104.6 | g |
|-------|----------------------------------|-------|-------|---|
|       | Solid waste [Waste for disposal]  | 14.49 | 1     | g |
|       | Ethanol/DES [hydrocarbon emission] | 144.49 | 41.093 | g |
|       | Electricity                       | 1.7   | 1.7   | kWh |

| Output | Total phenolic content [organics] | 104.6 | 104.6 | mg GAE/g |
|--------|----------------------------------|-------|-------|----------|
|        | Solid waste [Waste for disposal]  | 14.49 | 1     | g |
|        | DES/Ethanol [Waste for recovery]  | 144.49 | 0.0411 | g |

**Equipment**

All the equipment used in this present study is as follows, where initially the fruits were peel off to remove the seed from the peel and the pulp. Later, the peel and the pulp will be sold to third party for other purposes whereas the seeds will be stored in a freezer model Kirsch FROSTER-LABEX-530 at -20 °C for 24 hours. The freeze-drying of seeds was done in a Christ Alpha 1-4 LSC freeze dryer for 1 day to remove the moisture content in the seed [22]. According to [22], the water loss percentage of seed using freeze dryer as compared to oven drying is 51±6%. The authors reported that, high content of phenolic compounds was detected in freeze-dried seeds than any other drying treatments. Hence, in this study the water loss of seed in a freeze dryer was assumed to be the same as the previous study. The dried seeds were ground in a Cornell blender to obtain fine sample powder that is later sieve using a mesh of 0.025mm. The required amount of sample was weighed accordingly using a laboratory weighing scale with an accuracy of ±0.0001 g for extraction whereas the leftover was disposed to landfill. The electricity consumptions for all the equipment were estimated using Eq. 1 as shown below:

\[ E = Pt \]  

where,

- \( E \) = Electrical energy
- \( P \) = Power of equipment
- \( t \) = Time of electricity consumption

**Extraction of phenolic compounds**

SLE technique was performed using VorTemp 56™ shaking incubator to extract the samples [20] based on the optimum process condition for both the cases as shown in Table 3. The electricity consumption required for the extraction varies as the extraction temperature and time varies as shown in Table 2. Therefore, to manipulate the temperature between both cases, a water bath was added to heat up the DES mixture containing the seed sample. Besides, the electricity mix used for this present study is under Germany, as the electricity mix specifically for Malaysia is not provided in the trial version of GaBi. After extraction, the sample mixture was fed to a centrifuge machine to separate both supernatant and residue using Labnet Spectrafuge 6C Compact Research Centrifuge that was operated for 10 minutes [20]. TPC of 104.6 mg GAE/g sample were produced at the end of centrifugation for both cases. However, it is necessary to treat the extraction solvents used in the extraction of phenolic compounds. Therefore, two rotary evaporators of Rotavapor R-100 models were used for both cases. For the case 2 which uses ethanol as the extraction solvent, the first rotary evaporator was to evaporate ethanol whereas the second rotary evaporator was to remove water [23]. For the case 1 using DES as the green extraction solvent, the first rotary evaporator was to remove the water in DES phase and followed by second rotary evaporator to further remove the DES from the extract [24]. The inputs, outputs and electricity consumption for all the equipment used for both cases are as summarized in Table 2. Regarding the solid waste disposal and wastewater derived from the extraction and centrifugation steps were assumed to be the same amount of seed sample and water fed for the...
processes. Besides, it was assumed that zero losses in extraction solvent during both extraction and centrifugation.

**Table 2 Optimistic process conditions for both the extraction solvents**

| Extraction solvent | Temperature (K) | Time (min) | Solid/liquid ratio (g/mL) | Water addition /Concentration (100%) |
|--------------------|-----------------|------------|--------------------------|--------------------------------------|
| DES (ChCl: ethylene glycol) 1:4 | 313.15 | 100 | 1:10 | 10 |
| Ethanol | 303.15 | 30 | 1:100 | 50 |

2.1.6. Life cycle impact assessment (LCIA). The life cycle impact assessment (LCIA) for this present work was performed using GABI software and the environmental impact categories evaluated consist of global warming air including biogenic carbon (GWP, in), global warming air excluding biogenic carbon (GWP, excl), acidification (AP), eutrophication (EP), smog air, ecotoxic air, human health particulate air (HHPA), human toxicity, cancer effect (HTCE), human toxicity, non-cancer effect (HTNCE), ozone depletion (OD) and resources, fossil fuels (FF).

### 3. Results and Discussion

Table 4 and Table 5 summarized the environmental profile per FU (104.6 mg GAE/g sample) in terms of the environmental impact categories as mentioned. Due to the novelty of DES system, no comparison can be done with other studies on the environmental results obtained. The bars in the charts as shown in Fig. 3 and Fig.4 have been normalized considering all the processes for both cases as 100%. Negative values in the results indicate the environmental load decreasing whereas positive values indicate an increment in environmental load [21]. In order to have a better understanding on the environmental burdens from the solid-liquid extraction of phenolic compound from *D. rostrata* seed, the extraction process was divided into sub-processes. The sub-processes for case 1 using DES includes transportation, storage of seed, freeze-drying, grinding, DES preparation, SLE, centrifugation, rotary evaporator I and II as well as solid waste disposal and disposal storage of chemical for further treatment while, Case 2 using ethanol having the same sub-processes as case 1, except for the DES preparation which was substituted with dilution of ethanol. Hence, it was easier to compare the contribution of each sub-process to the environmental impact.

By comparing both data tabulated in Table 4 and Table 5, it can be concluded that SLE extraction step is the second most responsible to contribute high environmental impact after transport activities and electricity. SLE exerting a significant impact on the environment involves two different extraction solvents responding to electricity consumption. This is due to the additional heating of extraction mixture required for case 1 to meet the optimum extraction condition of 313.15K. Heating is known to be harmful to the environment. Hence, based on Fig.5 case 1 shows a global warming impact of 0.519 kg CO₂ eq that is much higher as compared to case 2 with a global warming impact of 0.156 kg CO₂ eq. Centrifugation, freeze-drying, grinding, storage of seed in a freezer and both of the rotary evaporator having the same electricity requirement, for both of the cases as the sub-processes operate under same process conditions. Hence, have no any significant changes between case 1 and case 2 in terms of their impact categories.

**Table 3 Results obtained for the impact categories of each sub-processes used to perform SLE extraction using DES (Case 1)**

| Impact category | Units | Centrifugation | DES preparation | Freeze drying | Grinding | Rotary evaporator 1 | Rotary evaporator 2 | SLE | Storage of seed |
|----------------|-------|----------------|-----------------|--------------|----------|---------------------|--------------------|-----|----------------|

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Apart from that, in terms of temperature effect, electricity consumption proved as the key factor due to its high importance in contributing all the categories of environmental impacts studied. Based on Fig.3 and Fig.4, this factor shows high significance in fact contributes 60 to 80% of the overall environmental impacts categories. In both cases, electricity is mainly consumed for heating, drying, cooling and mixing. However, freeze-drying shows the greatest environmental impact in terms of OD, HTNCE, HTCE and FF among all these equipment used to perform the extraction and it is not easy to substitute the energy source of a freeze dryer by different means of heating. Besides, storage of seed in a freezer also contributes a significant impact on the environment due to the amount of electricity required to store the seeds for a day.

**Table 4** Results obtained for the impact categories of each sub-processes used to perform SLE extraction using ethanol (Case 2)
Figure 3 Environmental profile of each sub-processes used to perform SLE extraction using DES (Case 1)

Figure 4 Environmental profile of each sub-processes used to perform SLE extraction using ethanol (Case 2)
Figure 5 The environmental profile of solid liquid extraction using DES and ethanol as the extraction solvent. Impact categories acronyms: GWP, in = global warming air including biogenic carbon, GWP, excl = global warming air excluding biogenic carbon, AP = acidification, EP = eutrophication, HHPA = human health particulate air, HTCE = human toxicity, cancer effect, HTNCE = human toxicity, non-cancer effect, ODP= ozone depletion and FF = resources, fossil fuels (FF)

Based on Fig.3, the DES preparation shows a negative ecotoxic air impact of 20%. This is because, DES is known as an environmental-friendly green solvent that is able to curb the toxic air produced instead of releasing it to the environment [9]. Concerning the transportation in supplying the chemicals and raw materials for the extraction process shows a remarkable impact as summarized in Table 5 in terms of global warming, ozone layer depletion, acidification and eutrophication due to the diesel and kerosene consumption in deriving combustion emissions. From Fig.3 and Fig.4, it can be clearly seen that the greenhouse gas emissions of 80-90 % is $CO_2$ that is mainly related to transport activities and followed by freeze drying.

Table 5 Results obtained for the impact categories of transport

| Impact category | Units       | Transportation of DES chemicals | Transportation of ethanol | Transportation of fruits |
|-----------------|-------------|---------------------------------|--------------------------|------------------------|
| GWP, incl       | kg $CO_2$ eq. | 31.1                            | 31.5                     | 833                    |
| GWP, excl       | kg $CO_2$ eq. | 30.8                            | 31.1                     | 833                    |
| AP              | kg SO$_2$ eq. | 0.174                           | 5.48E-02                 | 2.79                   |
| EP              | kg N eq.     | 0.011                           | 3.51E-03                 | 0.163                  |
| ODP             | kg CFC 11 eq. | 1.28                            | 1.28E+00                 | 91.9                   |
| Ecotox          | CTUe        | 0.00105                         | 1.05E-03                 | 0.0671                 |
| HHPA            | kg PM2.5 eq. | 5.29E-03                        | 1.07E-03                 | 0.0444                 |
| HTCE            | CTUh        | 1.38E-11                        | 1.38E-11                 | 2.97E-10               |
| HTNCE           | CTUh        | 1.09E-09                        | 1.09E-09                 | 2.18E-08               |
| FF              | MJ surplus energy | 1.48E-02                | 1.48E-02                 | 1.87E+00               |
| Smog air        | kg O3 eq.   | 1.67E-14                        | 1.67E-14                 | 5.21E-13               |

By observing the environment profile of both cases, ethanol appeared to a better extraction solvent as compared to DES by considering the extraction efficiency. This is due to the extraction time,
temperature as well as the choice DES combination to extract phenolic compounds from *D. rostrata* seed. In order to perform the extraction using DES, it required 100 minutes to produce achieve the FU whereas ethanol as the extraction solvent only required 30 minutes as shown in Table 3. Hence, as the extraction time increase, more electricity consumptions are required therefore, contributes to major environmental impacts. Besides, ethanol is a well-developed solvent used widely for the extraction of polyphenolic compounds from various plant materials using conventional extraction technique.

4. Conclusion
Based on the results, the extraction of phenolic compounds using both DES and ethanol were analysed and compared to study on the environmental profile of each sub-processes. SLE was found to be the second most important factor to exert greater impacts after transport activities and electricity. Global warming was the highest impact category in this study as the main contributions are from the transportation and freeze-drying. The main objective of this present study is to compare the potential environmental impacts of a lab scale SLE technique using two different extraction solvents, ethanol, and DES to extract phenolic compounds from *D. rostrata* seed under optimum process conditions. The LCA analysis demonstrated that the conventional extraction solvent, ethanol shows the least impact of environment especially in terms of electricity consumption. However, some of the points remain unclear, which indicates the need of future studies. The initial goal leads to reducing environmental impacts of extraction by using an environmentally friendly green solvent instead of a conventional solvent. Nevertheless, in this study this was not demonstrated quantitatively, hence further research needs to be done on analyzing various range of DES system ratio with a range of optimum process conditions experimentally instead of using secondary data to perform the LCA analysis.

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