

## The Development of Software for Assessment of Environmental Impact Indicators of Engineering Products by Using the Approach of Life Cycle Assessment (LCA) At Design Stage

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**Abstract:** Environmental preservation consciousness has become the theme of engineering industry. Therefore manufacturing of an engineering product must include the emissions, which emitted during the process right from 'cradle to grave'. These emissions, which are detrimental to the air, to the water and to the soil must be considered. Hence a concept of development of 'greener product' using 'greener processes' has become a popular among the manufacturer. Hence these emissions so emitted during the processes must be pre-calculated and if possible should be controlled during various stages of life cycle of the engineering product, such as raw material acquisition, manufacturing, assembly, transportation, usages to its final disposal. Internationally environmental impact assessment method is utilized which cover eco-system quality and human health. The method of determining these impacts universally based on technique of life cycle assessment, i.e. LCA. By this, impact indicator of various impact categories according to the selected LCA methods signifies the type of impact on the environment. The impact categories, normally effect the environment are Ecotoxicity water acute (EWA), Ecotoxicity water chronic (EWC), Ecotoxicity soil chronic (EWC), Human Toxicity Air (HTA), Human Toxicity water (HTW), Human Toxicity soil (HTS), Global Warming (WA), Acidification (AC), Terrestrial Eutrophication (TET), Aquatic Eutrophication (AET), Ozone depletion (OD), Ozone Formation Vegetation (OFV) and Ozone Formation Human (OFH). The Author has developed a software named as 'SSLCASoft' which covers features which can handle all kind of engineering products, i.e. 'Single Entity' and 'Multi Entity'. It can calculate impact indicators of various impact categories. It has built in features of computation of quantity impact evaluation process along with data storage in systematic manner. It is presented in four main modules with features such as 'data input', 'life cycle inventory', 'inventory filtration' and 'impact assessment'. Under impact assessment module, it covers and discussed the method of 'inventory processing & characterization' and 'impact evaluation' for calculating and graphically presenting the final impact assessment. Finally it is supported by two illustrations as case studies, such as 'engine cylinder as single entity product' and 'Engine group of two-wheeler as multi entity product' for validation and verification of 'SSLCASoft'.

**Keywords:** Environmental Impact, Impact Category, Impact Indicators, Impact Evaluation, Life Cycle Assessments, Life Cycle Inventory, Product Life Cycle Stages, LCA Methods, Manufacturing Processes, Raw Material Manufacturing, Part Manufacturing, Single Entity Product, Multi Entity Product,

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### I. Introduction

In the race of industrialization, the production of engineering goods and their services create impact on environment in the form of emission to atmosphere, which has harmful effect. Presently, the impact of products and their process right from 'cradle to grave' (right from procurement of material from mine to the final disposal of it after use.) on environment have become a key concern to the industry. Therefore manufacturing of an engineering product include the emissions which emitted are detrimental to the air, to the water and to the soil must be considered. Hence these emissions so emitted during the processes must be calculated and if possible should be controlled during various stages of life cycle such as raw material extraction, manufacturing, assembly, transportation, usages to the its final disposal.

The impacts on environment analyzed are internationally known as Environmental Impact Assessment 'EIA'. It normally covers two types of damages i.e. eco-system quality and human health (ref. 1). There is a technique which identify the detrimental effect by evaluating the impact indicators of impact categories (ref. 2) such as Ecotoxicity water acute (EWA), Ecotoxicity water chronic (EWC), Ecotoxicity soil chronic (EWC), Human Toxicity Air (HTA), Human Toxicity water (HTW), Human Toxicity soil (HTS), Global Warming (WA), Acidification (AC), Terrestrial Eutrophication (TET), Aquatic Eutrophication (AET), Ozone depletion (OD), Ozone Formation Vegetation (OFV) and Ozone Formation Human (OFH), which are the main constituent

for environment pollution. Each of these impact categories signifies the type of impact on the environment. To implement it, a universally known technique known as life cycle assessment 'LCA' (ref.3) is useful for evaluating the environment emission. It is very helpful tool for the manufacturers. The LCA are executed into four steps process i.e. goal and scope; inventory analysis; impact assessment and interpretation (ref.2). While executing LCA for a particular engineering product, it involves handling of huge amount of data during inventory processing and impact assessment under the different phases of LCA. The LCA method also helps manufactures for evaluating environmental emission at initial stage of design/ development/ or improvement. It can also provide a comparative emission estimate, if a product material substituted by another suitable material processing and impact assessment under the different phases of LCA. The LCA method also helps manufactures for evaluating environmental emission at initial stage of design/ development/ or improvement. It can also provide a comparative emission estimate, if product material substituted by another product material. Hence a concept of development of 'greener product' [ref.3], using 'greener processes' have become a popular among the manufacturer.

The author has developed a software named as "SSLCASoft". It is simple; user friendly; covers the features which can handle all types of engineering products 'single entity' and 'multi entity' with its components associated. It can estimate impact indicator of impact categories mentioned above. The built in features are computation of quantitative evaluation process along with data storage in a systematic manner. A broad line of 'SSLCASoft' is presented in a sequence and structured manner.

An engineering product may be 'single entity' i.e. the material of the main part and the sub parts are made of same or single material and 'multi entity' i.e. the material of the main part and the sub parts are made of different constituent materials and it may have assembly and subassembly. The paper deals to classify the Environmental Impact assessment. Environmental emissions of a product are a complex i.e. based on modeling the procedure of LCA. It needs/requires large number of relevant data, hence based on data-intensive. To calculate the impact categories of a particular product are by using ISO-14040 (ref.4) , that also help to identify the hot spots i.e. dominating impact categories . The software 'SSLCASoft' so developed is suitable to apply large variety of engineering Products. The software explained in to well defined steps and breakups and it spreads into number of models before its implementation. It operates smoothly and quickly without an error. The different outputs in the form of impact categories are presented conveniently into graphical output.

## **II. Software Structure, Modules With Their Features**

The software consist of four sub modules which are as under

1. Data Input
2. Life Cycle Inventory (LCI)
3. Inventory filtration
4. Impact Assessment

These are described as under

- 1. Data input:** The data input is fed with the help of different data input files. It has several 'master files' (such as product master, assembly master, subassembly master, partmaster, materialmaster, processgroup master), which are the 'data storage' files store the data.
  - a. It contains the product details; its assembly, sub assembly and components with its materials and sub-materials (such as plastic, steel, rubber, aluminium, fiber, cast iron, etc.).
  - b. Life cycle stages of the product (such as raw material acquisition, material manufacturing, part manufacturing, assembly, transportation and use).
  - c. Process groups (moulding, injection moulding, casting & machining, forging & machining, presswork & machining, rolling, machining etc.) and its manufacturing processes.
  - d. The impact categories of selected method of LCA out of the three methods i.e. EDIP; Eco-Indicator99 and FRED are evaluated. It includes three compartments along with their substances.[Ref. 5,6]
  - e. The developed 'SSLCASoft' has inbuilt function for conversion of units, i.e. method of unit normalization. The units of materials are in weight of 1 kg and the energy is taken as 1 MJ. The content of emissions of all responsible substances of this LCI (Life Cycle Inventory) is normalized in grams as weight, e.g. the total value of emission of substance in ng, µg, pg, etc. has been converted into gram 'g'. For the operation of machining the unit is in minutes.

### **2. Life Cycle Inventory (LCI)**

This module stores the life cycle inventory data of the engineering materials under consideration (as plastic, steel, rubber, aluminium, cast iron, and fiber) and its manufacturing processes, energy, transportation, and the fuel used.

LCI of above materials are collected [ref. 7-20] for four stages (raw material acquisition, material manufacturing, part manufacturing and assembly). All these details are stored in a file 'Input.LCI' in a systematic manner with proper classifications.

The LCI of substances like acetaldehyde, acetone, acetic acid, Benzene, Benzaldehyde, Chloroform, CFC, CO<sub>x</sub>, ethane, hexane, NO<sub>x</sub>, methane, SO<sub>x</sub>, toluene, VOC, xylene, etc. responsible for various impact categories are stored into 'substance master' with their characterization factor (char\_factor). [ref. 1,4,6]

The input is given in the form of different codes according to the 'type of material used' and 'the life cycle stage for which it is needed' and it is along with its 'manufacturing processes'.

The sample screen shots of LCI of engineering materials and LCI of manufacturing process are as shown in figure-1 and figure-2 respectively.

| Substance        | Compartment | Unit | Total    | Char_Factors |
|------------------|-------------|------|----------|--------------|
| SO3              | Air         | µg   | 20.5     | 0            |
| cyclohexane      | Air         | ng   | 729      | 0            |
| CO               | Air         | mg   | 47.716   | 0            |
| PAHs             | Air         | ng   | 0.19276  | 0            |
| o-xylene         | Air         | µg   | 35.6286  | 0            |
| cyclohexane      | Air         | ng   | 61.404   | 0            |
| Carbon disulfide | Air         | µg   | 59.658   | 0            |
| Carbon disulfide | Air         | µg   | 9.638    | 0            |
| antimony         | Air         | µg   | 1.3351   | 0            |
| As               | Air         | µg   | 31.126   | 0            |
| B                | Air         | mg   | 0.005111 | 0            |
| Ba               | Air         | µg   | 0.09085  | 0            |
| Be               | Air         | µg   | 1.6274   | 0            |
| benzene          | Air         | µg   | 98.75    | 0            |
| benzene sea      | Air         | ng   | 0.055063 | 0            |
| Cr               | Air         | µg   | 0.006873 | 0            |
| Bi               | Air         | ng   | 0.77815  | 0            |
| Cd               | Air         | µg   | 3.8473   | 0            |
| Chloroform       | Air         | µg   | 4.4398   | 0            |
| Chromium         | Air         | ng   | 0.24253  | 0            |
| CO (sea)         | Air         | mg   | 0.004543 | 0            |
| CO2              | Air         | g    | 199.87   | 0            |
| cobalt           | Air         | ng   | 0.013035 | 0            |

Figure-1: LCI of engineering materials

| Substance                   | Compartment | Unit | Total     | Char_Factors |
|-----------------------------|-------------|------|-----------|--------------|
| Carbon disulfide            | Air         | µg   | 59.658    | 0            |
| Energy in capital equipment | Non mat.    | kJ   | 4.401     | 0            |
| suspended solids            | Water       | mg   | 26.2593   | 0            |
| methyl ethyl ketone         | Air         | µg   | 183.375   | 0            |
| benzene                     | Air         | µg   | 611.25    | 0            |
| acetaldehyde                | Air         | µg   | 266.016   | 0            |
| antimony                    | Air         | µg   | 8.2641    | 0            |
| As                          | Air         | µg   | 192.666   | 0            |
| B                           | Air         | mg   | 0.0316383 | 0            |
| Ba                          | Air         | µg   | 0.56235   | 0            |
| benzene sea                 | Air         | ng   | 0.340833  | 0            |
| HCl                         | Air         | mg   | 552.57    | 0            |
| dioxin                      | Air         | pg   | 0.0144255 | 0            |
| Dioxin & Furans             | Air         | pg   | 806.85    | 0            |
| dust                        | Air         | mg   | 90.465    | 0            |
| ethylbenzene                | Air         | µg   | 49.878    | 0            |
| ethylbenzene (sea)          | Air         | pg   | 0.50856   | 0            |
| F                           | Air         | mg   | 70.416    | 0            |
| formaldehyde                | Air         | µg   | 158.925   | 0            |
| Be                          | Air         | µg   | 10.0734   | 0            |
| H2S                         | Air         | µg   | 0.192666  | 0            |
| cyclohexane                 | Air         | ng   | 84.108    | 0            |
| hexane                      | Air         | µg   | 31.1493   | 0            |
| Hg                          | Air         | µg   | 23.1297   | 0            |

Figure-2: LCI of Manufacturing Processes

### 3. Inventory filtration

LCI filtration are carried into groups

- Inventory filtration of engineering materials.  
And
- Inventory filtration of engineering manufacturing processes.

The emissions to environment depend upon selected method of LCA, material under consideration, its manufacturing processes. The inventory filtration is carried out for proper matching of available constituents of substances in the domain of impact category of the selected LCA method and that is in material or manufacturing processes, which are responsible for emissions to the environment. All these are explains with the flow charts as shown in the figure-3.

The classified filtered inventory data of material with manufacturing processes are stored with classified impact category in the database of 'SSLCASoft', which is used during the inventory processing and impact evaluation for product under analysis.

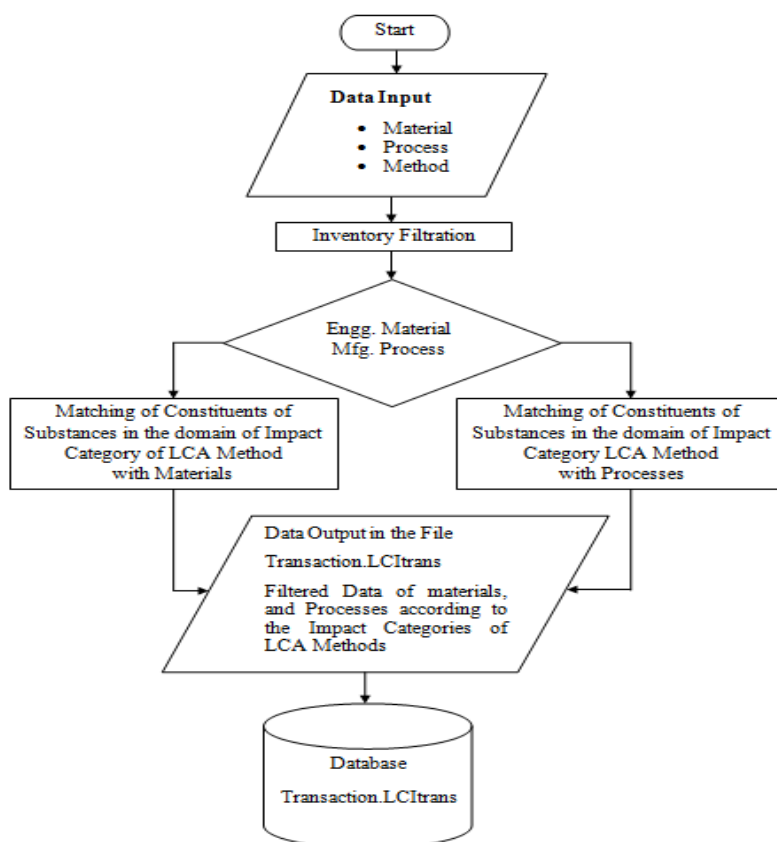


Figure-3: Flow chart for LCI Filtration

It is the matching of substances responsible for emissions of 'materials' and manufacturing processes with substances according to the impact categories (such as Ecotoxicity water acute, Ecotoxicity water chronic, Ecotoxicity soil chronic, Human Toxicity Air, Human Toxicity water, Human Toxicity soil, Global Warming, Acidification, Eutrophication, Ozone depletion, Ozone Formation) of the selected LCA method. The figure-4 and figure-5 shows the screenshot as sample for the inventory filtration-material wise and inventory filtration-process wise respectively.

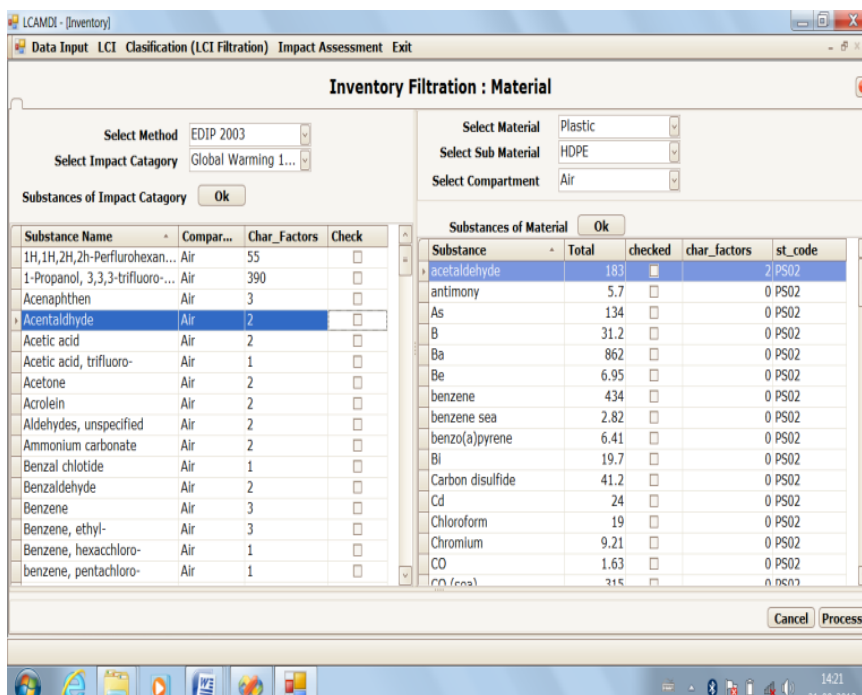


Figure-4: Inventory Filtration - Material wise

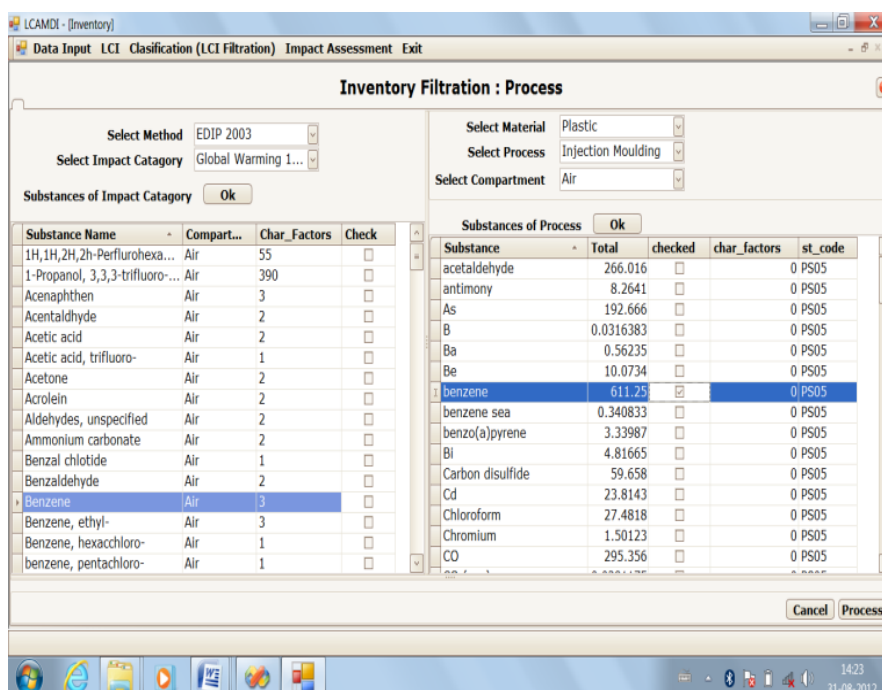


Figure-5: Inventory Filtration - Process wise

#### 4. Impact Assessment

The module evaluates the environmental impact of the product under investigation with given / specified boundary conditions. It is carried out in two steps:

- a. Inventory processing and characterization;
- b. Impact evaluation.

The results from this software provide the quantitative assessment of environment impact for different impact categories into graphical form.

It is applicable to both types of product i.e. single entity and multi entity. The process is demonstrated by a flow chart as shown in the figure-6.

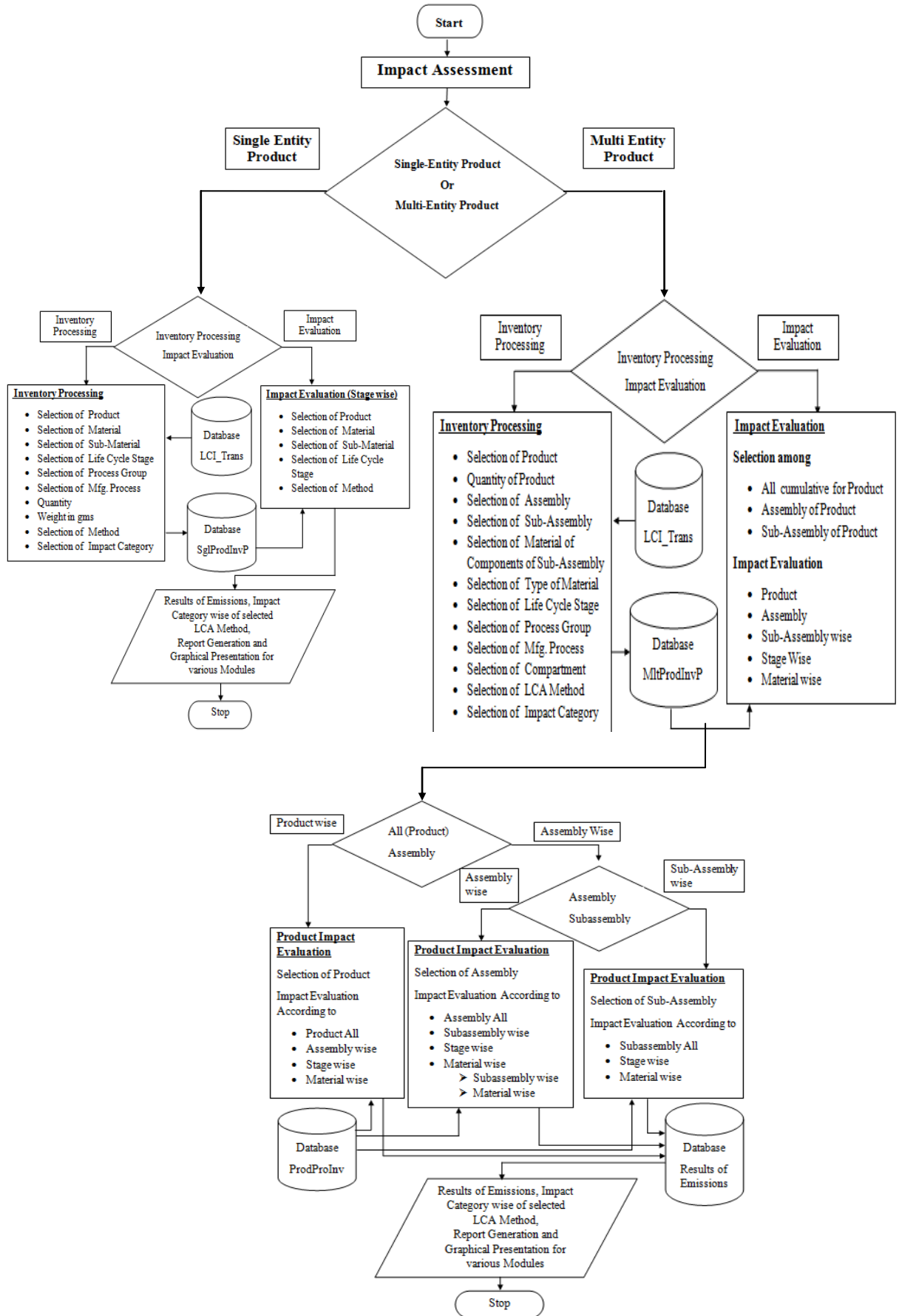


Figure-6: Flow chart for Impact Assessment

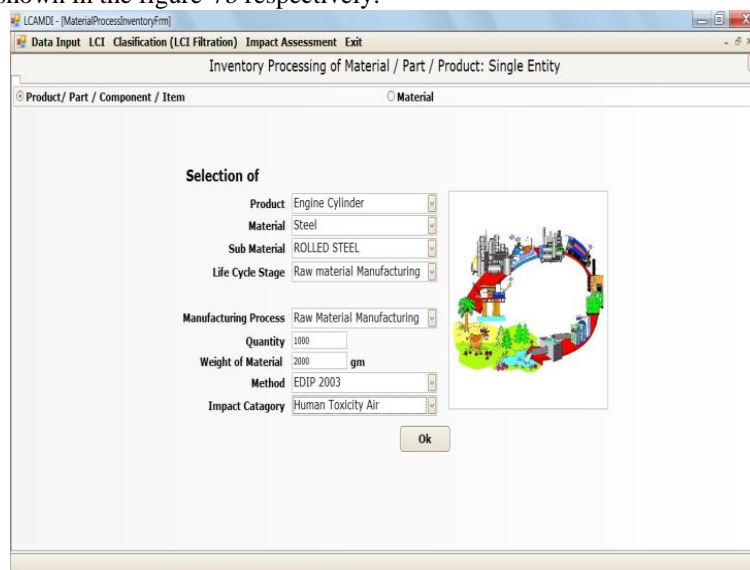
**a. Inventory processing and characterization**

The inventory processing is specifically carried out for the selected engineering product or its parts. The selection of the product is done with different aspects, such as assembly, subassembly, material, life cycle stage, process used, method and its impact category.

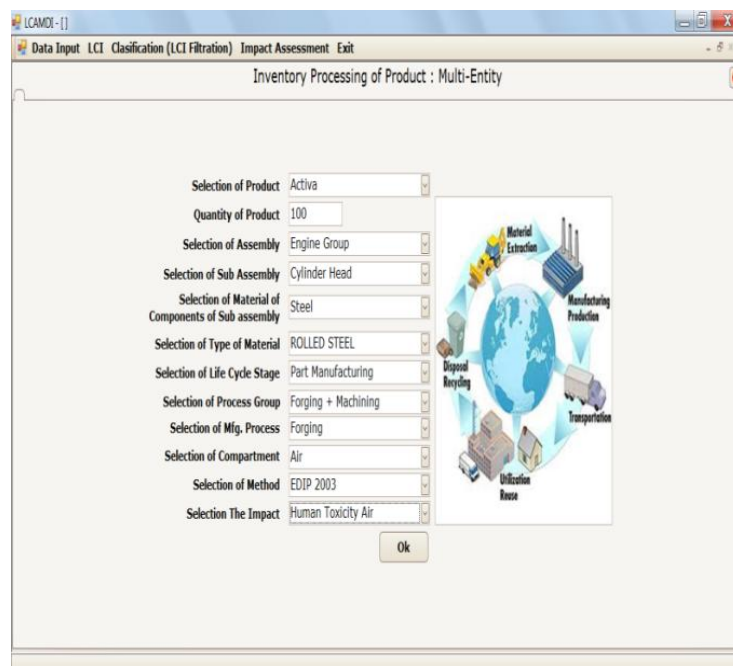
The databases of ProductMaster, AssMaster, SubAssMaster, StageMaster, MaterialMaster and 'LCITrans' are used as input for the inventory processing. The data are processed according to the particular combination of selection of above said different aspects. The LCI-data so obtained is stored in the database of 'SSLCASoft' material and impact category-wise.

The characterization factor is assigned to each substance of LCI, that is to be used for the process of characterization during this process of inventory processing. During 'Characterization', the processed LCI- data has been converted into the impact indicators. Then finally impact evaluation is carried out for the product.

The impact evaluations may be carried out for the 'single entity product'; and 'multi entity product'. The selection of different aspects during inventory processing for single entity is shown in the figure-7a, while for multi entity it is shown in the figure-7b respectively.



**Figure-7a: Inventory Processing of Single-Entity Product**



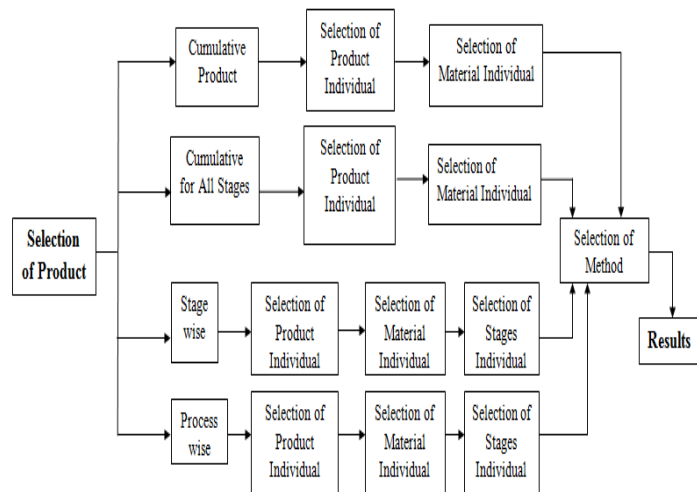
**Figure-7b: Inventory Processing of Multi-Entity Product.**



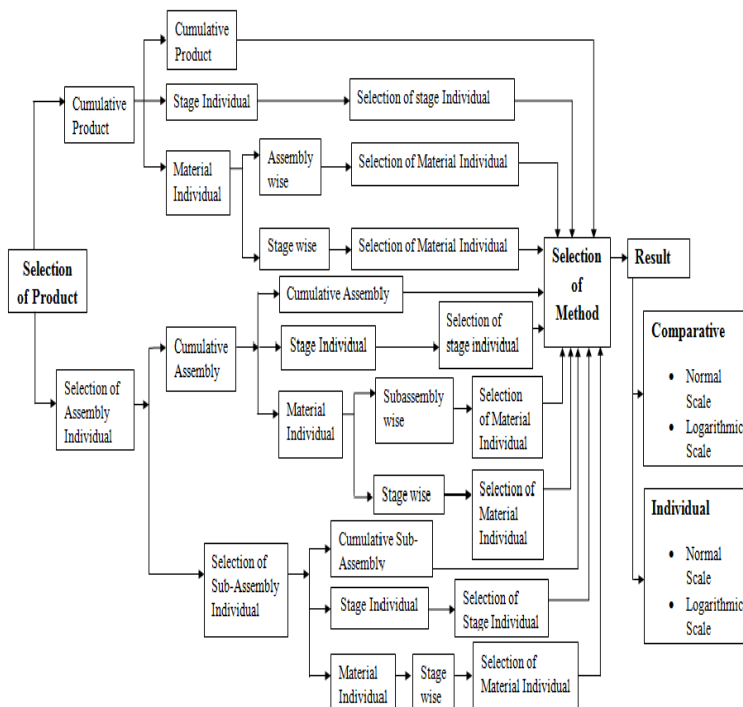
**b. Impact evaluation**

It may be noted that the engineering product however may consist of single part or having main part with group of assembly and subassembly, they made of different materials. The impact indicators for each material are further processed for generation of ‘impact evaluation’.

The generation of results for environmental impact evaluation is carried as per the desired criteria and combinations, explained by the block diagrams as shown in the figure-8a and figure-8b for ‘single entity’ and ‘multi entity’ respectively. This helps us to identify the areas, which have the scope for reducing the environmental impact.



**Figure-8a: Structure for generation of results of ‘Single-Entity Product’**



**Figure-8b: Structure for generation of results of ‘Multi-Entity Product’.**

The screen shots of impact assessment of ‘Single-Entity Product’ and ‘Multi-Entity Product’ are as shown in the figure-9a and in the figure-9b respectively.



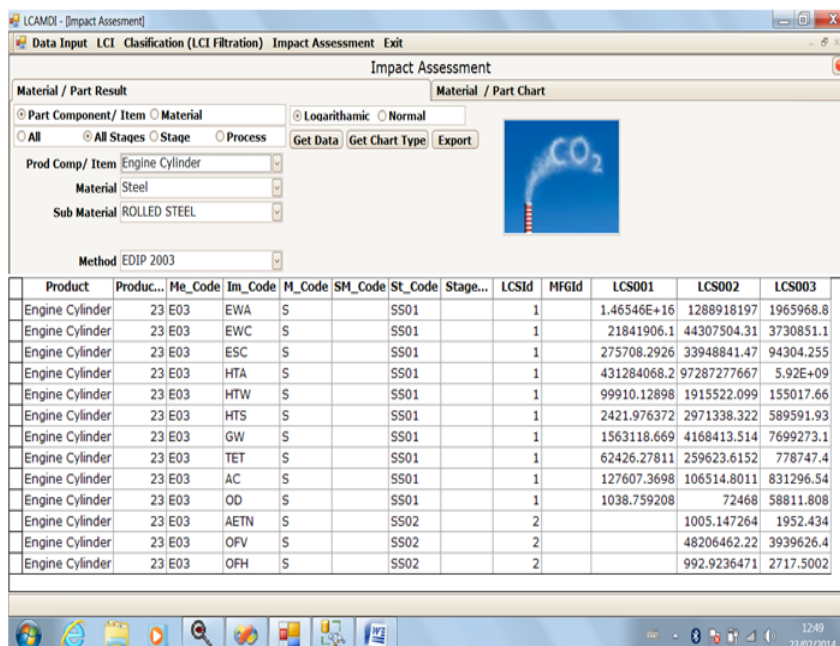


Figure-9a: Impact Assessment of 'Single-Entity Product'.

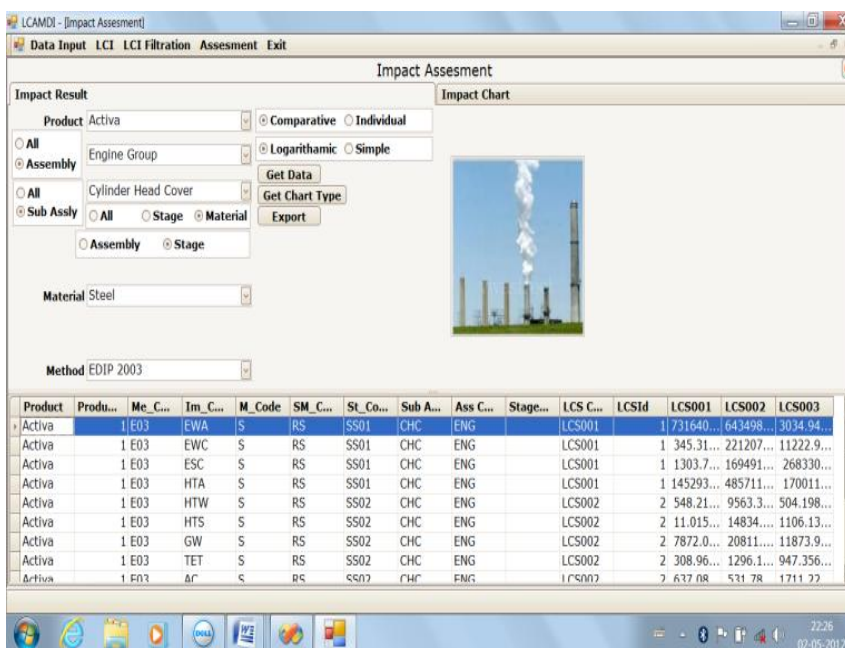


Figure-9b: Impact Assessment of 'Multi-Entity Product'

### III. Demonstration Of "SSLCASoft" Developed For Assessment Of Impact Indicators

In the developed software 'SSLCASoft', it has been verified that all related modules, i.e. (i) 'data input' of various aspects, such as product, assembly, sub-assembly, parts, material, life cycle stage, process group, manufacturing processes; (ii) 'life cycle inventory'; (iii) 'inventory filtration'; and (iv) 'inventory processing & impact evaluation under impact assessment' are performing according to their requirement of aim. Every previous module provides the desired output to the next module as input in correct desired form.

The demonstration of software for calculation of impact indicators on environmental impact is presented, briefly, the parts of two-wheeler of a scooter as case studies. They are:

- a. Engine cylinder Single entity, details are as per table-1
- b. Engine- group as multi entity; details are as per table-2

**Table-1:** details of engine cylinder

| Material of Part | Weight in gms |
|------------------|---------------|
| Steel            | 2000          |

**Table-2:** details of two-wheeler engine group

| Material of Parts | Weight in gms |
|-------------------|---------------|
| Plastic           | 606           |
| Steel             | 5992          |
| Rubber            | 207           |
| Aluminium         | 7080          |

The single entity product is made from one single material only; the details about material and weight of engine cylinder are as shown in the table-1. The multi entity product is having parts of different materials. The details about constituent materials of different parts of two wheeler engine group and their weights are as shown in the table-2.

**a. Generation of results for Engine Cylinder**

It is being engineering product of Single entity; the first step is the input of product is done in the product master. For impact assessment the next step is the inventory processing, that is carried out as per figure-7a. During this process, in order to calculate impact indicators of the Product, its material (steel), sub-material, life cycle stage (LCS), process group, its quantity, its weight, LCA method and its specific impact category are required to process in proper sequence. This processing is repeated to evaluate other impact categories of particular LCA method. Next for generation of results, refer the figure-8a, there are four criteria and combination for which the result for impact evaluation can be generated. Among these, for this specific case routed through, i.e. cumulative for all stage, stage-wise with selection of material and LCA method has been selected. The outcome of result, i.e. impact indicators for each impact categories and at each life cycle stages, such as raw material acquisition (LCS-01), material manufacturing (LCS-02), and part manufacturing (LCS-03) are as shown in the figure-9a. The results are presented graphically is shown in the figure 10a.

**b. Generation of results for Engine Group**

It is being multi entity engineering product; the first step is the input of the product is carried out in the respective product master. The input of its assembly groups, subassemblies and their respective parts has been done in assembly master and subassembly master and part master respectively. For impact assessment, the next step is the inventory processing, has been carried out for the product, as per figure-7b. During this process, in order to calculate the impact indicators, the selection of particular combination of the Product, its quantity, selection of assembly group, selection of subassembly, material of its parts, sub-material, selection of life cycle stage (LCS), selection of process group, its manufacturing process, LCA method and impact category are required to processed in proper sequence. The details of cumulative weight of all parts of selected subassembly has been automatically calculated and extracted from the part master. This processing is repeated for other combinations of different above said aspects and for all other impact categories of particular LCA method.

Next for generation of results, refer figure-8b. There are 11 combinations of various criteria, through which the impact evaluation can be carried out. Among these the route i.e. cumulative impact, which include all assembly groups having parts of all materials and for all life cycle stage, for selected impact category of selected LCA method, has been evaluated. The outcome of result, i.e. impact indicators for different impact categories are as shown in the figure-9b. The results presented graphically are shown in the fig.10b.

These results are presented graphically can be exported to other 'MSExcel' files. The ordinates depicts the magnitude of different Impact Indicators of different impact categories (listed into introduction) and they are calculate on the basis of commutative effect (emissions contributes in a particular categories by single substance or other substances and they are added together into a particular category), while abscissa represented by impact categories for different aspects, such as cumulative for whole product, Life cycle stage-wise & material-wise,(for both kind, single entity product and multi entity product) and assembly group-wise, sub-assembly-wise (for multi entity product only) etc.

In case of Engine cylinder, impact categories on abscissa shows stage wise. In case of Engine group the impact categories on abscissa are shown cumulatively.

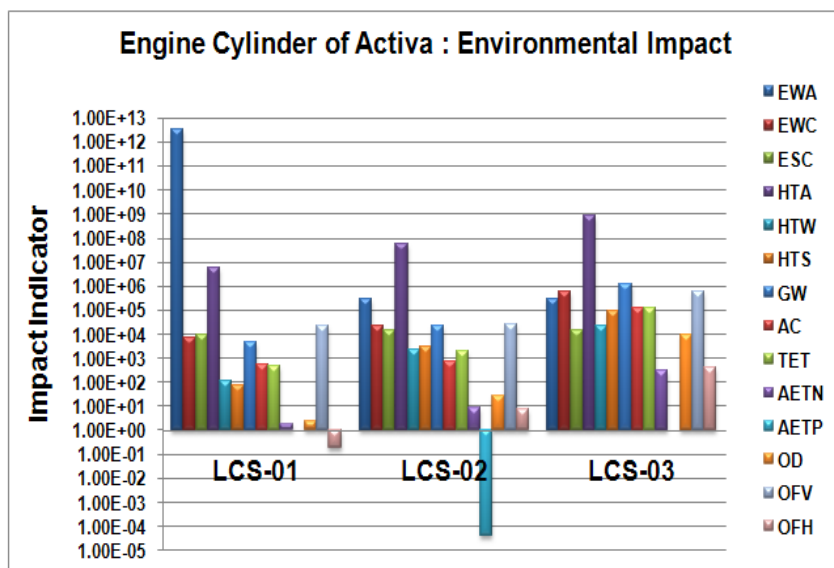


Figure- 10a: Graphical Presentation of Impact Assessment (stage-wise) of Engine Cylinder of ‘Activa’ ‘Single- Entity Product’

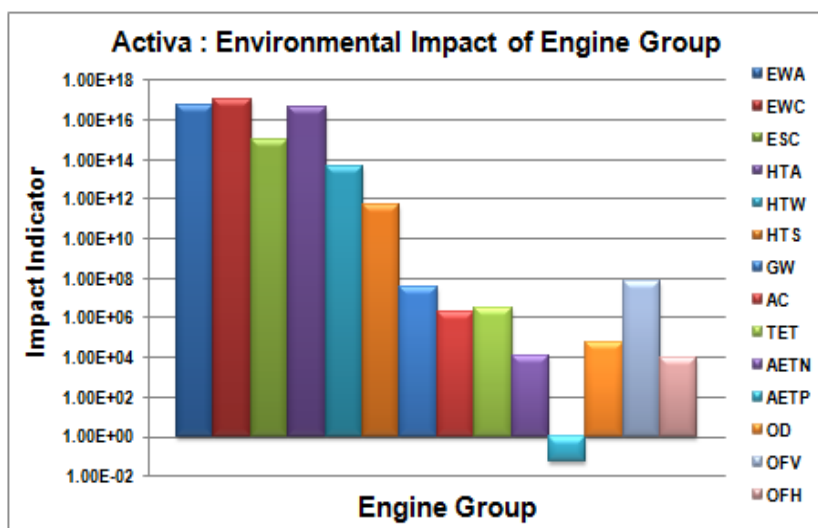


Figure-10b: Graphical Presentation of Impact Assessment (cumulative) of Engine Group of Activa: ‘Multi-Entity Product’

According to the aim, the developed software ‘SSLCASoft’ has been validated by the examples properly. The output results of the software are helpful for environmental impact assessment.

#### IV. Conclusions

Software ‘SSLCASoft’ presented has four modules which can handle both types of engineering products, i.e. single entity and multi entity with all components associated with it.

Module has provision of life cycle inventory data of specific materials along with LCI of substances for which environmental impact assessment are required by way of finding impact indicators. A detail flow chart for LCI filtration is provided in order to help the inventory processing and impact evaluation.

The process of environment impact evaluation of product fully illustrated with complete boundary conditions with flow chart for impact assessment.

A structure for generation of results for impact evaluation is provided for single / multi entity engineering product with simplified method of adoption of route for analysis for any new product.

An illustration is presented by giving the case studies of single entity product ‘Engine Cylinder’ and multi entity product ‘Two-Wheeler Engine Group’.

Software 'SSLCASoft' has inbuilt module to present the results in graphical format as impact indicators as ordinates and impact categories as abscissa along with distinct regimes of emissions with marked stages such as LCS-01, LCS-02 and LCA-03.

By using this software 'SSLCASoft' an estimate of impact indicators along with impact categories can be carried out at design stages of any engineering product. If some alternative material is substituted for the product by way of new design then the emissions can be estimated at design stage and then a comparison of emission can be done in interest of environment control.

The software 'SSLCASoft' is very versatile, user friendly, error free, produce expected results and helpful for environmental impact assessment.

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