6.1 NEED FOR ENVIRONMENTAL TAX IN INDIA

The assessment of the environmental status has shown the need for environmental tax in India. It is seen that emissions to the environment are mainly due to various forms of primary energy consumption, disposal of wastes and CFCs without recycling or proper care as well as production of secondary energy like electricity from coal-based power plants. Achievements in different forms of renewable energy generation have been showing an increasing trend, which is a welcome sign for reducing environmental pollution. Even though per capita emissions to the environment are far below that of the developed countries, India has taken stringent measures to reduce environmental pollution in various sectors. The analysis done mainly in transport and industrial sectors shows the severity of environmental pollution created by them. The greatest lacuna is the weak monitoring and enforcement of standards and legislation, which means norms achieved are lower than what have been expected. The devastating effect of climate change as a result of greenhouse gas emission strengthens the need for the introduction of environmental tax in India. Since India’s energy strategy is based on cheap domestic coal, which is of high carbon content and of low calorific value, implementation of carbon tax is not viable for a developing country like India. Hence, two environmental taxes are formulated and proposed for India based on Life Cycle Assessment (LCA) and exergy.
6.2 LIFE CYCLE ASSESSMENT

Jolly et al (A 5.1. 2005) have published the Life Cycle Assessment (LCA) of a refrigerator, one of the widely used thermal engineering appliances and the tax based thereon along with their results. The total pollution caused during the life cycle of the refrigerator in terms of CO₂, SO₂ and NOₓ has been evaluated. Impact assessment due to the above pollutants in terms of the environmental effects like global warming, ozone depletion and acidification and then a life cycle index has been calculated using these environmental effects and their weighting factors. The environmental tax based on LCA has been proposed proportional to the value of the life cycle index.

6.2.1 Pollution Caused from Raw Material Acquisition for the Refrigerator Parts

Total pollution caused from raw material production is calculated from the inventory of raw materials given in Table 6.1, electrical energy consumption for the production of various materials given in Tables 4.1 and 4.2 and emissions to the environment in the production of electrical energy from coal-based power plants given in Table 4.3 and presented in Table 6.1.

In calculating global warming in terms of CO₂ equivalents, global warming potentials given in Table 4.8 and the total pollution caused given in Table 6.1 are used in Equation (4.1). Ozone depletion in terms of R11 equivalents is calculated using the values given in Table 6.1 in Equation (4.2). Acidification in terms of SO₂ equivalents is calculated using total pollution caused given in Table 6.1 in Equation (4.3).
Table 6.1  Pollution Caused from Raw Material Acquisition for the Refrigerator Parts

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight CO₂</th>
<th>NO₂ × 10⁻³</th>
<th>SO₂ × 10⁻³</th>
<th>CO × 10⁻³</th>
<th>HC × 10⁻³</th>
<th>TSP × 10⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg Kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
</tr>
<tr>
<td>Copper</td>
<td>3.54 187.1</td>
<td>528.01</td>
<td>525.36</td>
<td>45.97</td>
<td>18.04</td>
<td>287.53</td>
</tr>
<tr>
<td>Steel</td>
<td>21.29 250.9</td>
<td>708.02</td>
<td>704.47</td>
<td>61.65</td>
<td>24.18</td>
<td>385.54</td>
</tr>
<tr>
<td>Aluminium</td>
<td>2.15 115.0</td>
<td>324.48</td>
<td>322.85</td>
<td>28.25</td>
<td>11.09</td>
<td>176.69</td>
</tr>
<tr>
<td>HIPS/ABS</td>
<td>7.4 566.6</td>
<td>1599</td>
<td>1591</td>
<td>139.2</td>
<td>54.2</td>
<td>870.72</td>
</tr>
<tr>
<td>Glass</td>
<td>0.78 6.88</td>
<td>19.41</td>
<td>19.32</td>
<td>1.69</td>
<td>0.66</td>
<td>10.57</td>
</tr>
<tr>
<td>P.E.</td>
<td>3.15 18.53</td>
<td>52.30</td>
<td>52.03</td>
<td>4.553</td>
<td>1.786</td>
<td>28.472</td>
</tr>
<tr>
<td>Rubber</td>
<td>0.5 4.34</td>
<td>12.27</td>
<td>12.21</td>
<td>1.068</td>
<td>0.419</td>
<td>6.68</td>
</tr>
<tr>
<td>Paint</td>
<td>0.5 169.0</td>
<td>476.85</td>
<td>474.47</td>
<td>41.52</td>
<td>16.29</td>
<td>259.67</td>
</tr>
<tr>
<td>N₂</td>
<td>2.5 8.46</td>
<td>23.88</td>
<td>23.76</td>
<td>2.08</td>
<td>0.816</td>
<td>13.008</td>
</tr>
<tr>
<td>LPG</td>
<td>0.75 0.007</td>
<td>3.20</td>
<td>6.33</td>
<td>0.554</td>
<td>10.20</td>
<td>0.375</td>
</tr>
<tr>
<td>Furnace oil</td>
<td>0.316 0.011</td>
<td>1.34</td>
<td>2.56</td>
<td>0.233</td>
<td>4.31</td>
<td>0.079</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.031 0.001</td>
<td>0.133</td>
<td>0.264</td>
<td>0.023</td>
<td>0.426</td>
<td>0.0156</td>
</tr>
<tr>
<td>PUF</td>
<td>0.015 18.53</td>
<td>52.31</td>
<td>52.05</td>
<td>4.55</td>
<td>1.787</td>
<td>28.48</td>
</tr>
<tr>
<td>Card board</td>
<td>3 4.685</td>
<td>13.22</td>
<td>13.154</td>
<td>1.254</td>
<td>0.456</td>
<td>7.2</td>
</tr>
<tr>
<td>SAE oil</td>
<td>0.15 0.014</td>
<td>0.636</td>
<td>1.313</td>
<td>0.008</td>
<td>2.743</td>
<td>0.175</td>
</tr>
<tr>
<td>Total</td>
<td>46.08 1350</td>
<td>3815.1</td>
<td>3801.2</td>
<td>332.6</td>
<td>147.4</td>
<td>2075.2</td>
</tr>
</tbody>
</table>

The results have been presented below:
- Global warming in CO₂ equivalents = 1430.04 kg
- Ozone depletion in R11 equivalents = 0.0158 kg
- Acidification in SO₂ equivalents = 6.47 kg
6.2.2 Pollution Caused During the Manufacture of Parts and Their Assembly

Total pollution caused during the manufacture of parts and their assembly is calculated from inventory given in Tables 4.4 to 4.7 and pollution caused during production of electrical energy from coal-based power plants given in Table 4.3 and summarized below:

<table>
<thead>
<tr>
<th>Gas Type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>68.017 kg</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>0.1919 kg</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>0.1910 kg</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.0160 kg</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>0.0066 kg</td>
</tr>
<tr>
<td>TSP</td>
<td>0.1045 kg</td>
</tr>
<tr>
<td>R11</td>
<td>0.0123 kg</td>
</tr>
<tr>
<td>R12</td>
<td>0.0033 kg</td>
</tr>
</tbody>
</table>

In calculating global warming in terms of CO\textsubscript{2} equivalents, global warming potentials given in Table 4.8 and the total pollution caused given above are used in Equation (4.1). Ozone depletion in terms of R11 equivalents is calculated using values given above in Equation (4.2). For calculating acidification in terms of SO\textsubscript{2} equivalents, total pollution caused given above is used in Equation (4.3). The results have been presented below:

- Global warming in CO\textsubscript{2} equivalents = 146.797 kg
- Ozone depletion in R11 equivalents = 0.0158 kg
- Acidification in SO\textsubscript{2} equivalents = 0.33 kg
6.2.3 Pollution Caused During Use, Service and Maintenance of the Refrigerator

Total environment pollution caused during use, service and maintenance of the refrigerator is calculated from the inventory given in sections 4.2.5 and 4.2.6 and pollution caused during the production of electrical energy from coal-based power plants given in Table 4.3. The results are:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>8690.58 kg</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>24.522 kg</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>24.34 kg</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>2.135 kg</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>0.8376 kg</td>
</tr>
<tr>
<td>TSP</td>
<td>13.353 kg</td>
</tr>
<tr>
<td>R12</td>
<td>0.011 kg</td>
</tr>
</tbody>
</table>

In calculating global warming in terms of CO$_2$ equivalents, global warming potentials given in Table 4.8 and total pollution caused given above is used in Equation (4.1). Ozone depletion in terms of R11 equivalents is calculated using values given above in Equation (4.2). For calculating acidification in terms of SO$_2$ equivalents, total pollution caused given above is used in Equation (4.3). The results are:

- Global warming in CO$_2$ equivalents = 8768.68 kg
- Ozone depletion in R11 equivalents = 0.0116 kg
- Acidification in SO$_2$ equivalents = 41.51 kg
6.2.4 Environmental Effects During the Post-use Phase of the Refrigerator

Since refrigerants are released to the environment without proper care, the environmental effects are calculated from the inventory of the refrigerants. In calculating the global warming in terms of CO$_2$ equivalents, global warming potentials given in Table 4.8 and inventory of the refrigerants given in section 4.2.7 are used in Equation (4.1). Ozone depletion in terms of R11 equivalents is calculated using the inventory of refrigerants given in section 4.2.7 in Equation (4.2). The results are:

- Global warming in CO$_2$ equivalents = 2626 kg
- Ozone depletion in R11 equivalents = 0.5264 kg

6.2.5 Summary of Impact Assessment for the Refrigerator

The summary of impact assessment due to raw material acquisition, manufacture and assembly, use, service and maintenance and disposal of the refrigerator is given in Table 6.2 below:

<table>
<thead>
<tr>
<th>Process</th>
<th>Environmental Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Global Warming kg of CO$_2$</td>
</tr>
<tr>
<td>Raw material acquisition</td>
<td>1430.040</td>
</tr>
<tr>
<td>Manufacture and assembly</td>
<td>146.797</td>
</tr>
<tr>
<td>Use, service and maintenance</td>
<td>8768.680</td>
</tr>
<tr>
<td>Disposal</td>
<td>2626.000</td>
</tr>
<tr>
<td>Total</td>
<td>12971.517</td>
</tr>
</tbody>
</table>
Contribution to global warming, ozone depletion and acidification by different stages of the life cycle of the refrigerator as percentages are shown in the Figures 6.1, 6.2 and 6.3.

**Figure 6.1  Contribution to global warming by different life cycle stages**

Figure 6.1 shows that the percentage contribution to global warming is highest from the use-stage and it is about 68%. Use of more efficient compressor reduces the energy consumption during the use-stage, which in turn reduces emission of CO$_2$, which is the main cause of global warming.

It is seen from Figure 6.2 that the percentage contribution to ozone depletion is the highest from the disposal-stage and is equal to about 92%. This is mainly due to the disposal of the refrigerants causing ozone depletion without proper care at the end of the useful life time of the refrigerator. By recycling the CFCs used as refrigerants, the ozone depletion effect can be reduced.

Figure 6.3 shows that the contribution by the use-stage is the highest to acidification and is about 86%. Use of more efficient compressor reduces the energy consumption and thereby acidification effect.
Figure 6.2  Contribution to ozone depletion by different life cycle stages

Figure 6.3  Contribution to acidification by different life cycle stages

6.2.6  Formulation of Life Cycle Index for the Refrigerator
Life Cycle Assessment has been extended to define a single score called Life Cycle Index, summarizing the environmental effects like global warming, ozone depletion and acidification and the weighting factors for the corresponding environmental effects from Table 4.9 as given below:

\[ \text{Life Cycle Index is formulated as } 2.5 \times CO_2 + 100 \times R11 + 10 \times SO_2 \] (6.1)

Life cycle index for the refrigerator is calculated with the environmental effects given in Table 6.2 in Equation (6.1) and presented in Table 6.3.

**Table 6.3  Life Cycle Index for the Refrigerator**

<table>
<thead>
<tr>
<th>Processes</th>
<th>Life Cycle Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material acquisition</td>
<td>3641.13</td>
</tr>
<tr>
<td>Manufacture and assembly</td>
<td>371.87</td>
</tr>
<tr>
<td>Use, service and maintenance</td>
<td>22337.96</td>
</tr>
<tr>
<td>Disposal</td>
<td>6617.64</td>
</tr>
<tr>
<td>Total</td>
<td>32968.60</td>
</tr>
</tbody>
</table>

The contribution by different life cycle stages to life cycle index is shown in Figure 6.4 and it is seen that the use-stage contributes highest to the life cycle index and the next highest is from the disposal-stage. The contribution by the use-stage to life cycle index can be reduced by reducing the energy consumption during the use-stage because these emissions are due to the production of energy mainly from coal-based power plants in India. Emissions due to the disposal of the refrigerants without proper care contribute 20% to the life cycle index, which can be reduced by recycling of the refrigerants.
Contribution to various life cycle stages as reflected by life cycle index

Figure 6.4

Contribution to various environmental damages as reflected by life cycle index is shown in Figure 6.5.

Figure 6.5

Contribution to various environmental damages as reflected by life cycle index

Figure 6.5 shows that the highest contribution of 98.36% to the life cycle index is from global warming which can be controlled by reducing the
emission of CO$_2$ during the production of energy from coal-based power plants.

6.2.7 Life Cycle Assessment based Environmental Tax

Life Cycle Assessment (LCA) based environmental tax is formulated as proportional to the life cycle index and the tax rate has been taken as one rupee per 100 units of the value of the index so that the tax for refrigerators will be well within the compliance by the tax payer.

\[
LCA \text{ based environmental tax} = \frac{1}{100} \left[ 2.5 \times CO_2 + 100 \times R11 + 10 \times SO_2 \right] (6.2)
\]

Life Cycle Assessment based environmental tax for the refrigerator is calculated to be Rs.330 (~7.5$) using Equation (6.2).

6.3 COMPUTATION AND VALIDATION OF INDICES FOR NORMALIZATION

Formulation of two indices for normalization of data used for LCA using Buckingham Pi theorem and their validation is presented in this section. Also another index is formulated for fixing the boundary of LCA.

6.3.1 Computation and Validation of Technology Transfer Index

Technology Transfer Index (TTI) is formulated considering the average values of the Productivity Index ($P$), Percentage of Employment ($E$), Population per square kilometre ($S$) and Coal Power-plant Efficiency ($\eta$). Average values of the factors considered for developed countries are represented by suffix 1 and the corresponding values for developing countries are represented by suffix 2.
Non-dimensional Pi groups considered are:

\[ \pi_1 = P_1/P_2 \]  
\[ \pi_2 = E_1/E_2 \]  
\[ \pi_3 = S_1/S_2 \]  
\[ \pi_4 = \eta_1/\eta_2 \]  

Since TTI is directly proportional to the Pi groups,

Technology Transfer Index is formulated as

\[ \frac{P_1 \times E_1 \times S_1 \times \eta_1}{P_2 \times E_2 \times S_2 \times \eta_2} \]  

TTI has been calculated by substituting the values from Tables 4.10 to 4.13 in Equation (6.7) and is found to be 1.60.

Validation of the index is done using the energy intensity for the production of steel in the USA and in India given in Section 4.7.1 and found to be 1.55. Again the value of the index is calculated using the energy intensity for the production of aluminium in Australia and in India given in Section 4.7.1 and found to be 1.545. The error in the value of TTI is around 3.4%.

6.3.2 Computation and Validation of Human Health Index

In order to normalize the available database required for health impact assessment in LCA, Human Health Index (HHI) has been formulated using Buckingham Pi Theorem with average values of Calories Intake (C), Protein Intake per capita (PI) and Percentage Vaccination (V) for developed and developing countries. Suffix 1 represents average values for developed countries and suffix 2 represents the average values for developing countries.
Non-dimensional Pi groups considered are:

\[ \pi_1 = \frac{C_1}{C_2} \quad (6.8) \]
\[ \pi_2 = \frac{PI_1}{PI_2} \quad (6.9) \]
\[ \pi_3 = \frac{V_1}{V_2} \quad (6.10) \]

Since HHI is proportional to the Pi groups considered,

\[ Human Health Index is formulated as \quad \frac{C_1 \times PI_1 \times V_1}{C_2 \times PI_2 \times V_2} \quad (6.11) \]

HHI is calculated substituting the values from Table 4.14 in Equation (6.11) and is found to be 1.86.

Validation of the HHI is done considering the health impact due to automobile pollution in the USA and in India as follows:

Health impact values for India are calculated using the corresponding values for the USA and Gross National Product (GNP) for the USA and for India given in Table 4.16 and presented in Table 6.4.

<table>
<thead>
<tr>
<th>Emissions</th>
<th>Health Impact Valuations, $/1000 tonnes/person</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Premature Morbidity</td>
</tr>
<tr>
<td>SPM</td>
<td>19.2×10^{-4} – 28.9×10^{-4}</td>
</tr>
<tr>
<td>SO₂</td>
<td>31.2×10^{-5} – 642×10^{-5}</td>
</tr>
<tr>
<td>NOₓ</td>
<td>43.4×10^{-5} – 578×10^{-5}</td>
</tr>
</tbody>
</table>

Total damage cost is calculated using the population of the USA given in Table 4.16 and automobile emission rates and total health impact values for the USA given in Table 4.17 and presented in Table 6.5.
Table 6.5  Damage Cost for the USA

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Total Damage Cost, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPM</td>
<td>$28.260 \times 10^7 - 42.4 \times 10^7$</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>$0.369 \times 10^7 - 5.16 \times 10^7$</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>$5.790 \times 10^7 - 7.72 \times 10^7$</td>
</tr>
</tbody>
</table>

Total annual damage cost in $ = 34.42 \times 10^7 - 55.28 \times 10^7$

The automobile emission rates for India calculated using the values in Table 4.18 are given in Table 6.6.

Table 6.6  Automobile Emission Rates for India

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Automobile Emission Rates tonnes/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPM</td>
<td>$728.38 \times 10^5$</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>$3.59 \times 10^5$</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>$223 \times 10^5$</td>
</tr>
</tbody>
</table>

Total health impact values for India for each of the pollutants is calculated from Table 6.4 and entered in Table 6.7 below. Also total damage cost is calculated by multiplying the automobile emission rates for India given in Table 6.6, total health impact values given in Table 6.7 and population of India given in Table 4.16 and presented in Table 6.7 below.
Table 6.7  Health Impact Values and Damage Cost for India

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Total of Health Impact Values, $/1000 tonnes/person</th>
<th>Total Damage Cost $</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPM</td>
<td>$28.83 \times 10^{-4} - 43.35 \times 10^{-4}$</td>
<td>$17.84 \times 10^7 - 26.84 \times 10^7$</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>$47.26 \times 10^{-5} - 674.00 \times 10^{-5}$</td>
<td>$0.014 \times 10^7 - 0.021 \times 10^7$</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>$57.85 \times 10^{-5} - 597.22 \times 10^{-5}$</td>
<td>$1.096 \times 10^7 - 11.31 \times 10^7$</td>
</tr>
</tbody>
</table>

Total annual damage cost in $\$ = 18.96 \times 10^7 - 38.17 \times 10^7$

Total annual damage cost for USA in $\$ = \frac{34.42 \times 10^7}{18.96 \times 10^7} = 1.82$

The percentage error in validation of HHI is about 2.15%.

6.3.3  Computation of Boundary Fixing Index

Boundary Fixing Index (BFI) is formulated using Product Life time in years ($t_p$), Re-use Factor ($RF$), Exposed Damage Factor ($D$), Technology Factor ($TF$) and Atmospheric Life time in years ($t_A$) in Buckingham Pi theorem. There are five variables (m) and one fundamental dimension (n). Therefore according to the Pi theorem (m-n) which is (5-1) = 4 Pi terms needed for index formulation.

$RF$, $D$ and $TF$ are dimensionless parameters. So they are considered directly as Pi terms.

\[ \pi_1 = RF \] \hspace{1cm} (6.12)
\[ \pi_2 = D \] \hspace{1cm} (6.13)
\[ \pi_3 = TF \] \hspace{1cm} (6.14)
\[ \pi_4 = \frac{t_p}{t_A} \]  

(6.15)

Since BFI is directly proportional to \( \pi_2 \) and \( \pi_3 \) and inversely proportional to \( \pi_1 \) and \( \pi_4 \).

Boundary Fixing Index is formulated as
\[ \frac{D \times TF \times t_A}{RF \times t_p} \]  

(6.16)

BFI is calculated with the values from section 4.7.3 in Equation (6.16) as follows:

\[
\text{BFI for developing countries} = \frac{10.86 \times 0.12 \times 27.4}{3 \times 18} = 0.661
\]

\[
\text{BFI for developed countries} = \frac{10.86 \times 0.486 \times 27.4}{1 \times 11} = 13.29
\]

The boundary fixing index value indicates that for developed countries, it is high, meaning the effects in raw material acquisition, manufacture and assembly and also waste disposal should be incorporated in addition to the environmental effects during the use-stage. Whereas for developing countries, the BFI is low, indicating that the effects during the use-stage alone need to be considered.

### 6.4 EXERGY ANALYSIS OF THE REFRIGERATION CYCLE

Since the operating conditions vary for different types and models of refrigerators, detailed exergy analysis is carried out with variations in some of the parameters like isentropic compressor efficiency, ambient air temperature, evaporator exit temperature and condenser temperature. The capacity of the refrigerator is 0.08 TR. The cold room and the ambient air temperatures are assumed to be 0°C and 20°C, respectively. The condensing temperature is taken constant at 30°C. The isentropic compressor efficiency is
varied from 65% to 85%. The evaporator exit temperature is varied between \(-20^\circ C\) and \(-5^\circ C\). Percentage exergy loss in each component of the refrigerator is calculated and presented in the form of graphs in Figures 6.6 to 6.10 with % exergy loss Vs $\frac{T_c}{T_c - T_e}$. In the first case, the compressor efficiency is assumed as 65%. Percentage exergy loss in each component of the refrigerator is calculated and presented in the form of graphs in Figure 6.6.

The exergy loss in the evaporator decreases with the increase in the evaporator temperature because lower the temperature difference, lower will be the exergy loss. As the total percentage exergy loss at any evaporating temperature is 100%, the decrease in the percentage exergy loss in the evaporator is made up by the increase in the exergy loss in the condenser. Due to the corresponding increase in the exergy loss in the other components, the increase in the exergy loss in the condenser is not as prominent as the decrease in exergy loss in the evaporator as seen in the Figure 6.6.

![Figure 6.6 Effect of $T_c$ and $T_e$ on % Exergy loss](image)
The analysis is repeated with compressor efficiency of 70%, 75%, 80% and 85% and the graphs are shown in Figures 6.7 to 6.10.

Figure 6.7  Effect of $T_c$ and $T_e$ on % Exergy loss

Figure 6.8  Effect of $T_c$ and $T_e$ on % Exergy loss
In Figure 6.7 also the exergy loss in the evaporator decreases with the increase in the evaporator temperature because of the lower temperature difference. There is increase in the exergy loss in all the other components. Figure 6.8 also shows a decrease in exergy loss in the evaporator.

\[
\frac{T_c}{T_c - T_e}
\]

Figure 6.9  Effect of $T_c$ and $T_e$ on % Exergy loss

In Figure 6.9, the exergy loss in the compressor is again reduced due to the increased compressor efficiency. The exergy loss in the evaporator is reducing due to the lower temperature difference and there is an increase in the exergy loss in the condenser as well as in the other components.

In Figure 6.10, the decrease in the exergy loss in the evaporator is very predominant due to the decrease in the difference in temperatures between the evaporator and the cold room when the evaporator temperature increases. The increase in the exergy loss in the compressor is not so predominant because of the increase in the exergy loss in the other components. The exergy loss in the compressor is also reduced due to the increased compressor efficiency.
All the graphs in Figures 6.6 to 6.10 shows that the exergy loss in the evaporator decreases predominantly with the increase in $\frac{T_c}{T_c - T_e}$ and there is increase in exergy loss in the condenser. This increase is not so predominant due to the increase in exergy loss in all the other components.

The analysis is also done at condenser temperature of 301 K and the effect of ambient temperature on percentage exergy loss in the various components at various compressor efficiencies from 65% to 85% at an interval of 5% as shown in Figures 6.11 to 6.15.

It is seen from the Figure 6.11 that the exergy loss in the condenser decreases predominantly with increase in the ambient temperature because when the ambient temperature increases, the difference between the condenser temperature and the ambient temperature decreases.
The analysis is repeated with a compressor efficiency of 70%, 75%, 80% and 85% and the graphs are shown in Figures 6.12 to 6.15.
Figure 6.13  % Exergy loss Vs Ambient temperature

Figure 6.14  % Exergy loss Vs Ambient temperature
Figures 6.11 to 6.15 show a predominant decrease in the percentage exergy loss in the condenser with the increase in the ambient temperature. This trend can be explained by the fact that the temperature difference between the condenser and the ambient air decreases with increase in ambient temperature. The analysis is repeated by changing the condenser temperature to 303 K and keeping all the other parameters constant.

Figure 6.16 Effect of $T_0$ on % Exergy loss with compressor $\eta = 65\%$
Figure 6.17 Effect of $T_0$ on Exergy loss with compressor $\eta = 70\%$

Figure 6.18 Effect of $T_0$ on Exergy loss with compressor $\eta = 75\%$

Figure 6.19 Effect of $T_0$ on Exergy loss with compressor $\eta = 80\%$
The figures show predominant decrease in the percentage exergy loss in the condenser at constant condenser temperature of 303 K due to the decrease in the difference in temperature between the condenser and the ambient air.

Since the decrease in percentage exergy loss in the condenser was pronounced, the analysis is repeated with condenser temperature 307 K and results are shown in Figures 6.21 to 6.25.
Figure 6.21 shows a predominant decrease in the percentage exergy loss in the condenser due to the decrease in the difference between condenser temperature and the ambient temperature.

![Figure 6.21](image1)

**Figure 6.22  Effect of $T_0$ on Exergy loss with compressor $\eta = 70\%$**

![Figure 6.22](image2)

**Figure 6.23  Effect of $T_0$ on Exergy loss with compressor $\eta = 75\%$**

![Figure 6.23](image3)
Figure 6.24  Effect of $T_0$ on Exergy loss with compressor $\eta = 80\%$

Figure 6.25  Effect of $T_0$ on Exergy loss with compressor $\eta = 85\%$
The analysis is repeated with condenser temperature of 313 K and the results are shown in Figures 6.26 to 6.30.

**Figure 6.26** Effect of $T_0$ on Exergy loss at $T_c=313$ K & $\eta_{\text{Compressor}}= 65\%$

**Figure 6.27** Effect of $T_0$ on Exergy loss at $T_c=313$ K & $\eta_{\text{Compressor}}= 70\%$

**Figure 6.28** Effect of $T_0$ on Exergy loss at $T_c=313$ K & $\eta_{\text{Compressor}}= 75\%$
In all the above cases it is seen that the percentage exergy loss in condenser decreases predominantly with the increase in the ambient temperature.

The study of exergy loss for variations in the compressor efficiency, the condenser temperature and the ambient temperature is essential for tax calculations. It is found that the compressor efficiency is inversely proportional to the exergy loss and hence to the tax. More efficient compressors will result in low tax. The condenser temperature also plays a vital role. It is directly proportional to the exergy loss and hence the tax. Contrary to this the exergy loss is inversely proportional to the ambient temperature. If the ambient temperature of the region is high then the exergy loss will be low and hence the tax.
6.5 FORMULATION OF TAX BASED ON EXERGY

Jolly et al (A 5.2. 2006) have reported a proposal for exergy based environmental tax for a refrigerator. They have done the calculation of the tax analytically and also using nomograms. In cases where it is easy to achieve reduction in exergy loss, the tax proposed is more so that the manufacturers will be forced to implement the modifications; if not they will have to pay a heavy tax. Exergy based tax is defined using exergy loss, weightage factor ($R$) and degree of difficulty ($dd$) factor for each of the components of the refrigerator, namely compressor, condenser, expansion valve and evaporator as follows.

$$Exergy\ based\ tax = 10\% \times E_x \times R \times dd^{-1}$$ (6.17)

Computation of exergy loss, weightage factor, degree of difficulty and exergy based environmental tax for the refrigerator and preparation of nomograms as a ready reckoner for calculation of tax are explained in the following sections.

6.5.1 Exergy Loss in the Components of the Refrigerator

The exergy loss in each of the components of the refrigerator is analyzed using computer programme and presented in Table 6.8.

Table 6.8 Exergy Loss in the Refrigerator Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Exergy Loss, kW</th>
<th>Exergy Loss, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>0.02136</td>
<td>47.17</td>
</tr>
<tr>
<td>Condenser</td>
<td>0.01257</td>
<td>27.74</td>
</tr>
<tr>
<td>Expansion valve</td>
<td>0.00595</td>
<td>13.13</td>
</tr>
<tr>
<td>Evaporator</td>
<td>0.00541</td>
<td>11.95</td>
</tr>
<tr>
<td>Total</td>
<td>0.04529</td>
<td>100</td>
</tr>
</tbody>
</table>
6.5.2. Formulation of Weightage Factor for Refrigerator Components

The weightage factor (R) is calculated from the extra investment for modification for the reduction in exergy loss and the corresponding reduction in exergy loss.

\[
\text{Extra investment to be made/kW} = \frac{\text{Extra investment for reducing the exergy loss}}{\text{Reduction in Exergy Loss}} \quad 6.18)
\]

Highest value of extra investment/kW reduction in exergy loss is for compressor equal to 37790.62Rs/kW. So the maximum value for the extra investment to be made/kW reduction in Exergy Loss is taken as 40,000 and then R is taken as zero. By iteration it is found that when extra investment to be made/kW reduction in Exergy Loss is zero; weightage factor is 25,000 for exergy based tax of about 5% of the cost of the refrigerator.

So the equation for calculating weightage factor is

\[
R = 25,000 - \frac{25,000}{40,000} \times \frac{\text{Extra investment to be made for modification}}{\text{kW reduction in Exergy Loss}} \quad 6.19)
\]

6.5.3 Formulation of Degree of Difficulty for Refrigerator Components

The degree of difficulty is a new factor proportional to the difficulty in reducing the exergy loss in the component. The degree of difficulty for the thermodynamic process in a refrigeration cycle are newly defined on a 0 to 1 scale, with 0 for very easy and 1 for very difficult. The degree of difficulty is derived from the pay back period using a nomogram.
Degree of difficulty ———

| 0 for very easy to reduce the exergy loss |
| 1 for very to difficult reduce the exergy loss |

The degree of difficulty (dd) is calculated using the payback period. The degree of difficulty is also calculated using calibrated nomogram. Payback period is the ratio of the extra cost to be invested for the modification and the total savings per year. The total savings per year is calculated from the reduction in exergy loss and the cost of energy. The efficiency of conversion of shaft work to electricity is assumed to be 75% in calculating the savings per year. Hours of operation per day for the air conditioner are taken as 14 hrs and the cost of energy as Rs 3.5/kW.

Savings in exergy loss per year = Exergy loss (17.361 from Table 6.9) × Efficiency of conversion of shaft work into electricity (assumed as 75%) × Hours of operation of an air conditioner (14 hrs/day) × No of days/year (364) × Cost of energy (Rs3.5/kW)  

\[
\text{Payback period} = \frac{\text{Extra cost to be invested for modifications for reducing the exergy loss}}{\text{Savings in exergy loss per year}} 
\]  

\[
\text{Degree of difficulty} = \frac{\text{Payback period}}{\text{Maximum Payback Period}} 
\]  

Maximum Payback Period is taken as 5Years. Degree of difficulty is assumed as 1 for a payback period of 5years.
6.5.4 Weightage Factor and Degree of Difficulty for Refrigerator Components

The weightage factor and degree of difficulty for the refrigerator components namely compressor, condenser, expansion valve and evaporator are calculated and presented in Appendix 4. The values obtained for weightage factor and degree of difficulty for the various components of refrigerator are given in Table 6.9.

<table>
<thead>
<tr>
<th>Component</th>
<th>Extra investment/ kW Loss Rs/kW</th>
<th>Weightage Factor Rs/kW</th>
<th>Pay back Period Years</th>
<th>Degree of Difficulty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressor</td>
<td>34,790.62</td>
<td>3,255.86</td>
<td>2.6</td>
<td>0.52</td>
</tr>
<tr>
<td>Expansion Valve</td>
<td>22,991</td>
<td>10,630.54</td>
<td>1.72</td>
<td>0.34</td>
</tr>
<tr>
<td>Evaporator</td>
<td>9,870</td>
<td>18,835.23</td>
<td>0.74</td>
<td>0.15</td>
</tr>
<tr>
<td>Condenser</td>
<td>6,793.35</td>
<td>20,754.15</td>
<td>0.506</td>
<td>0.10</td>
</tr>
</tbody>
</table>

The exergy tax is formulated with weightage factor and degree of difficulty in such a way that in cases where it is easy to achieve reduction in exergy loss, the tax proposed is more so that the manufacturers will be forced to implement the modifications; if not they will have to pay a heavy tax.

6.5.5 Calculation of Exergy based Tax for the Refrigerator

Exergy loss in various refrigerator components given in Table 6.8 and weightage factor and degree of difficulty given in Table 6.9 have been used in Equation (6.17) for computation of exergy based tax for the components of the refrigerator and presented below:

Compressor = Rs. 13.37
Condenser = Rs. 257.56
Expansion Valve = Rs. 18.40
Evaporator = Rs. 69.10
Total tax for the domestic refrigerator = Rs. 358.43 (~8$)

6.6 COMPUTATION OF EXERGY BASED ENVIRONMENTAL TAX USING NOMOGRAMS

The nomograms for the computation of the exergy based environmental tax for compressor is shown in Figures 6.31 and 6.32.

In Figure 6.31, nomogram [1] (line connecting scales A and B) is drawn with extra investment for reduction in exergy loss on scale A having a value of Rs. 604000, for which, the corresponding reduction in exergy loss on scale B being 17.361 kW. The result from nomogram [1] gives the extra investment per exergy loss to be 34790.62 Rs./kW and is shown on scale B’.
This value is transferred to scale B” for drawing Nomogram [2]. Nomogram [2] (line connecting scales B” and D) is drawn with the extra investment per exergy loss on scale B” and the maximum value for the weightage factor, which is calculated by iteration as 25000 on scale D. The result from nomogram [2] gives weightage factor equal to 3255.86 Rs./kW shown on scale D’. The third nomogram [3] (line connecting scale A and scale C) is drawn with extra investment for reducing exergy loss on scale A equal to Rs. 604000 and savings per year due to the reduction in exergy loss on scale C which is equal to 232251 Rs./year and result gives the a payback period equal to 2.6 years shown on scale C’. The maximum payback period is assumed to be five years for the analysis and taken on Scale E. The Nomogram [4] (line connecting scales C’ and E) with pay back period equal to 2.6 years and the maximum payback period equal to five Years, which
gives the value of the degree of difficulty for the compressor on scale $E'$ equal to 0.52.

Figure 6.31  Exergy based environmental tax for compressor [Part 1]

In Figure 6.32, the values of weightage factor equal to 3255.86 Rs./kW and degree of difficulty equal to 0.52 are represented on scales $D'$ and $E'$ respectively. The next nomogram [5] (line connecting scales $D'$ and $E'$) gives the value for tax per kW exergy loss equal to 6259.74 on scale $F$. The input here namely the exergy loss in the compressor of the refrigerator equal to 0.02136 kW represented on scale $G$ is taken from Table 6.8. The nomogram [6] (line connecting scales $F$ and $G'$) is drawn with tax per kW exergy loss equal to 6259.74 Rs./kW on scale $F$ and the exergy loss in the compressor equal to 0.02136 kW on scale $G'$. This results in the exergy based environmental tax equal to Rs.13.37 on the Scale H.
The procedure is repeated and the exergy based tax is calculated using the nomogram for all the other components also.

6.7 SENSITIVITY ANALYSIS FOR LIFE CYCLE ASSESSMENT BASED TAX MODEL

The Life Cycle Assessment (LCA) based environmental tax model has been formulated as proportional to the newly formed Life Cycle Index, and given in Equation (6.2). Sensitivity analysis of the model is done with a variation of -50% to +50% to values of CO$_2$, R11 and SO$_2$ in Equation (6.2). The variation is shown in Figure 6.33 below:
It is seen from Figure 6.33 that LCA based tax model is very sensitive to the values of CO$_2$, marginally sensitive to the values of SO$_2$ and least sensitive to the values of R11. Since for a very small change in CO$_2$ values, there is major change in the model output, very accurate calculations have to be performed in the case of CO$_2$ in the LCA model.

### 6.8 SENSITIVITY ANALYSIS FOR EXERGY BASED TAX MODEL

In the sensitivity analysis of exergy based tax model, evaluation is done with variation of -50% to +50% to the exergy based tax for each of the components. Exergy based tax for compressor, condenser, expansion valve and the evaporator have been calculated. The model evaluation has been done and the graphs are drawn in Figure 6.34.
From the Figure 6.34, it is seen that the exergy based tax model is very sensitive to the tax for condenser, marginally sensitive to the tax for evaporator and least sensitive to the tax for expansion valve and compressor. The tax rate for the condenser has been fixed high because it is easy to achieve reduction in exergy loss by proper modifications.

6.9 PUBLIC ACCEPTANCE SURVEY AND ANALYSIS

In the first round of the survey conducted using Delphi technique, 350 questionnaires were sent to selected users and manufacturers of refrigerators. Out of this, 166 responses were received back. Questionnaires with the consolidated results of the first round analysis, along with the choice of the corresponding respondent in the first round were prepared and sent again to all the 166 respondents of the first round with a request for the new responses if any. 84 people responded in the second round.
6.9.1 Analysis of the Delphi Responses

The analysis of the responses was carried out and group stability and individual stability were checked with the calculated and the table values of $\chi^2$ with their Degrees of Freedom (DOF) given in Table 6.10.

Table 6.10 Computed and Table Values of $\chi^2$ at Significance Level of 0.5

<table>
<thead>
<tr>
<th>Q. No.</th>
<th>Individual Stability $\chi^2$</th>
<th>Group Stability $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Computed</td>
<td>DOF</td>
</tr>
<tr>
<td>1</td>
<td>66.63</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>68.18</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>57.80</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>72.57</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>92.33</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>44.91</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>101.3</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>64.18</td>
<td>9</td>
</tr>
<tr>
<td>9</td>
<td>78.24</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>83.76</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>110.4</td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>92.81</td>
<td>9</td>
</tr>
<tr>
<td>13</td>
<td>29.14</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>120.4</td>
<td>9</td>
</tr>
<tr>
<td>15</td>
<td>39.06</td>
<td>1</td>
</tr>
<tr>
<td>16.1</td>
<td>15.76</td>
<td>4</td>
</tr>
<tr>
<td>16.2</td>
<td>7.514</td>
<td>4</td>
</tr>
<tr>
<td>16.3</td>
<td>2.667</td>
<td>4</td>
</tr>
<tr>
<td>16.4</td>
<td>6.083</td>
<td>4</td>
</tr>
<tr>
<td>16.5</td>
<td>14.23</td>
<td>4</td>
</tr>
<tr>
<td>16.6</td>
<td>2.60</td>
<td>4</td>
</tr>
<tr>
<td>16.7</td>
<td>2.00</td>
<td>4</td>
</tr>
<tr>
<td>16.8</td>
<td>21.59</td>
<td>4</td>
</tr>
<tr>
<td>16.9</td>
<td>17.38</td>
<td>4</td>
</tr>
<tr>
<td>16.10</td>
<td>16.03</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>82.00</td>
<td>9</td>
</tr>
</tbody>
</table>
From the Table 6.10, it is found that the computed value is higher than the table value only for 2 cases out of 26 cases, at a significance level of 0.5. Hence null hypothesis is accepted, and the group stability is said to be present in 92.3% of the cases. Comparing the calculated and the critical $\chi^2$ values, it has been found that the calculated value is higher than the table value in 21 out of 26 cases. This indicates that the null hypothesis is rejected at a significance level of 0.5. Thus accepting the alternate hypothesis shows that the individual responses in the two rounds are dependent and individual stability is present in 80.8% of the cases.

The variation of the standard deviation with the average confidence from round I to round II has been plotted and shown in Figure 6.35.

![Figure 6.35 Variations in average confidence and standard deviation from Round I to Round II](image)

The Figure 6.35 gives the measure of deviation and confidence and it is seen that out of 26 cases only in 5 cases the confidence is decreasing.

Difference in standard deviation and difference in confidence are plotted in Figure 6.36. In Figure 6.36, the distance of points from the origin
indicates the amount of change in standard deviation and confidence. It may be seen that majority of the points lie in the fourth quadrant, which shows increasing confidence and decreasing deviation. Out of the 26 points 20 points are in the (+, −), acceptable 4th quadrant, one is in the (+, +), 1st quadrant, four are in the (−, −), 3rd quadrant, and only one is in the unacceptable (−, +), 2nd quadrant. Hence it may be concluded that consensus has been achieved in 25 cases out of 26 cases.

Figure 6.36  Plots of confidence level and standard deviation for Delphi analysis

Analyses were carried out, using SPSS software, for the 84 responses of the second round. Percentage response for each choice was computed for all 84 responses, consisting of 60 responses from users and 24 responses from the manufacturers. The results of the analyses are presented below in Figures 6.37 to 6.52.

The assessment of the environmental degradation in 2005 by the respondents is shown in Figure 6.37.

It is seen from Figure 6.37 that on an average 76.2% of the respondents have said that there is considerable danger due to the degradation
of the environment. The environment enthusiasts have stated that the world is moving towards an acute dangerous level of pollution. But, only 12.5% of the manufacturers and 15% of the users accepted this fact. This shows the need for creating awareness about the environmental degradation and the danger the world is facing. In the absence of such an activity any effort to initiate environmental pricing policy will not gain any appreciation from the public.

![Percentage Responses](image)

**Figure 6.37 Assessment of environmental degradation in 2005**

Even though use of CFCs has been banned all over the world, it is being phased out in India in a staggered manner. Our country is the largest producer of CFC in the world and knowledge about this fact is found to be missing among manufacturers as well as users.

Only 8.3% and 10% of the manufacturers and users respectively have said that India stands first in CFC production as shown in Figure 6.38. It is strange to note that 58.3% of the manufacturers have opted not to comment, which reflects the interest level in environment related issues and facts.
With regard to the perception on the rate of deforestation in India represented in Figure 6.39, 37.5% of the manufacturers and 3.3% of the users have opted not to comment. Only about 25% of the manufacturers and 11.7% of the users have indicated the correct answer of 5%.

![Figure 6.38 Knowledge of India’s place in the world in CFC production](image1)

![Figure 6.39 Knowledge about the rate of deforestation in India](image2)
Figure 6.40 shows the responses of the users and the manufacturers with regard to the awareness of the commonly used environmental terms such as International Organization for Standards (ISO) 14000, Environmental Protection Agency (EPA), Life Cycle Assessment (LCA) and Genuine Progress Index (GPI). Here again 21.7% of the users and 75% of the manufacturers have said no comments. This strengthens the need for creating awareness among both the users and the manufacturers.

![Graph showing awareness about the environmental terms]

**Figure 6.40  Awareness about the environmental terms**

With regard to the understanding of the awareness level of the respondents, about the continuous triangle sign, more than 82.1% of the respondents have said either environment friendly or recyclable material, which is acceptable. This level of awareness has to be brought in all areas of concern with respect to environment. The trends are shown in Figure 6.41.
Having understood the awareness level of the respondents, the next focus has been to get their opinion on some vital issues, which are directly related to the acceptance of the environmental tax by the users as well as the manufacturers. Figure 6.42 shows the responses of the users and the manufacturers with regard to the best method to prevent pollution in India. Options given in the questionnaire are:

(i) Supplying environment friendly products free of cost
(ii) Creating greater awareness among public
(iii) Give subsidy for environment friendly products
(iv) Heavy penalty for polluting industries
Figure 6.42  Methods to prevent pollution

It is found from Figure 6.42 that 80% of the users and 92% of the manufacturers have opted for creating greater awareness among public as the best method to prevent pollution. About 7% of the users have opted for heavy penalty, whereas in the case of manufacturers the percentage was 4%. It is clear that only a negligible number of people opt for supply of environment friendly products free of cost. This again gives confidence that the respondents have really thought about the different aspects of the methodologies. The pollution prevention will be more effective by creating greater the awareness among the public about the best method to prevent pollution.
The experience of many nations who are levying environmental taxes shows that it also brings about side effects, in addition to fulfilling its prime objective of reducing the pollution. The possible side effects of levying the environmental tax are demand for the product may go down because of a higher price tag, manufacturer may become environment friendly or tax burden may be transferred to the public by way of higher price. Responses of the users as well as the manufacturers are shown in Figure 6.43.

![Figure 6.43 Effect of environmental taxing](image)

Figure 6.43 shows that majority of the users and the manufacturers (63.3% and 83.3% respectively) are of the opinion that the environmental tax burden will be transferred to the users, which is a negative sign.
The results of the analysis directly reflect the reactions of the users and the manufacturers. The perception of one on the other is also studied. Mutual understanding will help in combating the environmental effects, more efficiently.

![Percentage Responses](Image)

**Figure 6.44** Responses about the reactions to the environmental tax from public and manufacturers

As shown in Figure 6.44, the options given by the respondents about possible reactions of public and manufacturers are positive to the introduction of environmental tax. About 65% of the users and 66.7% of the manufacturers feel that the public will welcome environmental tax. However, the point to be noted here is that about 23.3% of users and 12.5% of manufacturers feel that the manufacturers will vehemently oppose the environmental tax. This may be due to the lack of awareness among manufacturers about the environmental degradation and its impact. There is also some apprehension about the price rise.
Figure 6.45 shows that about 76.7% of the users and 37.5% of the manufacturers have said that the environmental taxes can have direct influence on revenue generation, employment opportunities and international co-operation.

**Overall**

![Diagram showing the distribution of responses among users and manufacturers for employment opportunities, revenue generation, and international co-operation.]

No Comments – 2.3%

**Manufacturers**

![Diagram showing the distribution of responses among manufacturers for employment opportunities, revenue generation, and international co-operation.]

No Comments – 8.4%

**Users**

![Diagram showing the distribution of responses among users for employment opportunities, revenue generation, and international co-operation.]

Figure 6.45  Possible side effects of environmental taxes in India
On an average 85.7% of the respondents are for environmental damage based taxing. Only 2.4% of the respondents opted for fixed tax rate. Hence it is concluded that some taxing methodology based on environmental damage has to be evolved. The responses are shown in Figure 6.46.

![Figure 6.46 Basis of environmental tax](image)

About 71.7% of the users and 66.63% of the manufacturers prefer the environmental tax rate, as 5% of the cost, which is shown in Figure 6.47. Hence this factor also should be taken into account while fixing the tax rate, even though tax rate of 10% has been suggested by about 17.9% of the total respondents.

When the environment tax is levied, there is a strong possibility that the burden will be transferred to the public, by way of increased price. This may increase government revenue, but will in no way reduce the pollution and environmental damages. The options given by the respondents about various strategies are shown in Figure 6.48.
Figure 6.47 Accepted rate of environmental taxation

Figure 6.48 Best options for environmental taxation
The options given were:

(i) Fixed pricing policy, which will prevent the manufacturers from raising the price.
(ii) Heavy taxing, so that if the price is increased that will cause a fall in the demand of the product.
(iii) Very low taxing, so that even if it is transferred to the public, it will not be a big burden for them.
(iv) Low taxing with other disincentives or penalties.

Even if the burden is transferred to the public, because of the penalty levied from the manufacturers, there will be reduction in environmental damage. The manufacturers object to heavy taxing. None of the manufacturers have said yes to that. Many preferred the 3rd and 4th option. About 65.5% suggested low taxing and 17.8% for low taxing with disincentives and penalties as shown in Figure 6.48. Hence it is suggested that, in addition to taxing, an additional penalty clause should be there to combat environmental degradation.

Other issues considered were, whether the tax should be for component or system and direct tax or indirect. About 77.4% of the respondents have opted for taxing the system and the results have been shown in Figure 6.49.
With regard to direct or indirect method of taxing, 66.7% preferred direct taxing. These are shown in Figure 6.50.

The responses of the people for not accepting the environmental tax are projected in Figure 6.51. Three factors that occupy the minds of the people are that market demand will go down, loopholes will be created and competition among nations will reduce.
Figure 6.50  Mode of environmental taxation
Figure 6.51  Reasons for not favouring environment tax

About 77.4% of respondents are of the opinion that the government should take major role in introducing the environmental tax and it is shown in Figure 6.52.
The Life Cycle Assessment (LCA) of the refrigerator has been done and the LCA based index has been calculated as approximately equal to 32970. The LCA based environmental tax has been calculated as Rs.330 (~7.5$), which comes to be one Rupee per unit of the value of life cycle index. Two indices have been formulated using Buckingham’s Pi theorem and validated for normalization of the LCA data. Also an index has been formulated for fixing the boundary of LCA and for finding the significance of the various stages so that insignificant stages can be eliminated from the analysis. Another environmental tax based on the exergy
has been formulated for the refrigerator components and the total tax for the refrigerator has been calculated as approximately equal to about Rs.358.43 (~8$). Nomograms are constructed as a ready reckoner for calculating the exergy based environmental tax instantaneously. Sensitivity analysis showed that the changes in the values of CO$_2$ in the LCA based tax calculations and changes in the values of the exergy loss in the condenser in the exergy based tax calculations are the most sensitive. Delphi survey has been conducted and the analysis of the responses shows that the people are willing to pay 5% of the cost of the equipment as environmental tax. The taxes have been calculated with LCA and exergy and are found that the tax rates in both the cases are well within this acceptable limit of 5% of the cost of the refrigerator.