Sustainability Measurement Criteria for Ecological Footprint
campus Worksheet of Debre Berhan University, Ethiopia, East
Africa
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Abstract: Ecological footprint is a measurement tool to find out the land and water area any given human population requires for the production of their resources and the absorption of their wastes which is necessary for assessing the environmental impacts (Baboulet, O., & Lenzen, M. (2010) and their resource consumption. This tool is significant enough to identify the sustainable practices in the campus area of the university by calculating and analysing the Ecological footprint of the given area. It is imperatively an eco-friendly approach for the sustenance of environment and its resources on a long term basis. This methodology followed in this paper helps to identify, quantify the consumption of various resources and to evaluate the practices being followed in the university campus area.

Keywords: Yield factors, Equivalence factors, Ecological footprint, Sustainability

I. INTRODUCTION

Ecological footprint analysis (Chambers, and Wackernagel, 2000)) is an environmental assessment tool utilized with specific objectives to quantify the resource waste output which in turn, helps to evaluate the waste management practices and to perform the sustainability analysis (Alshuwaikhat, H. M., & Abubakar, I. 2008) by choosing an appropriate methodology for the given area. This method cannot directly convert the resource consumption into global hectares. Rather, first the area covered under land or water is calculated in hectares by dividing the total amount of resources to the average resource yield of the given resource harvested area, multiplied with both yield factors and equivalence factors. Mathis Wackernagel and William Rees (Wackernagel, M. and Rees, W. 1996) introduced the concept of Ecological Footprint Analysis and this technique has evolved gradually in the last two decades. Sustainability analysis helps to achieve the long term sustainable goals by resolving social, economic (Bennett, M., Hopkinson, P., & James, P. 2006) or environmental issues.

II. MATERIALS AND METHODS

The study area is chosen in the Ethiopian regional context with the deep rooted background of uneven resource utilization in this country of Sub-Saharan Continent. Natural resources are used in the given area beyond sustainable yield leading to negative environmental impacts. The city Of Debre Berhan is located in North Shewa Zone of Amhara Region, Ethiopia. The topography of the area is inundated with significant variations both in the elevation and temperature tributes within few miles of this city. The area is covered by 92% cropland and animal husbandry is the main occupation of this area heavily relying on the biomass resources including agricultural residue, wood wastes as well as livestock residues. The city is divided into various woredas whose number in total comes to be 500 and 307 woredas out of these are heavily utilizing woody biomass in excess of the sustainable yield. In the given background context of the city the study area of Debre Berhan University is well perceived to show environmental impacts which can be assessed by using the Ecological Footprint analysis methodology. Since the study area is well placed within the heart of the city and reserved within the boundary of the city it became easy to collect the data on regular basis. This method cannot directly convert the resource consumption into global hectares (Venetoulis, J. 2001). Rather, first the area covered under land or water is calculated in hectares by dividing the total amount of resources to the average resource yield of the given resource harvested area, multiplied with both yield factors and equivalence factors (Venetoulis, J. 2001). Mathis Wackernagel and William Rees introduced the concept of Ecological Footprint Analysis and this technique has evolved gradually in the last two decades.
1.2.1 RESEARCH DESIGN
The total area of productive land and hydrospace is estimated which is utilized for university campus resources’ consumption (Conway, T. M., Dalton, C., Loo, J., & Benakoun, L. 2008) and waste absorption over a period of one year. The consumption includes resources of various types like water use, fossil fuels, energy use, recyclable and non-recyclable material use in the university campus area.

1.2.2 DATA COLLECTION
The university population data is collected by taking personal interviews, questionnaires (both open-ended and close-ended) and specific departmental surveys. The administrative offices like University Registrar office and the Human Resource department provided ample information about the university population and other quantitative data.

1.3 THEORY/CALCULATION
1.3.1 INPUT FACTORS
Various consumption resources are used as input data into unit less values and this is converted in the form of consumption of land area of that country as given in Table A.1. The Equivalence factor is used to describe the productivity of any land type as compared to the world average productivity. Different land types are combined together taking single unit of measurement, common global hectare. These factors are multiplied by world average land productivity to measure the productivity of the land type (Hempel, L., Venetoulis, J., Gin, J. and Obazyae, S. 1998).

1.3.2 CALCULATION OF PAPER CONSUMPTION
Calculating Equation:
\[
\frac{\text{Consumption(reams)}}{435 (\text{reams/tonne})} \times (1.32 \frac{\text{ha}}{\text{yr/tonne}})
\]

As given in Table A.2 of Appendix
A tonne of virgin paper requires 1.8 m$^3$ of wood and the world average yield is 1.99 m$^3$ per ha per year \[\text{(Chambers, Simmons, Wackernagel. 2000. Sharing Nature’s Interest. London. p.93).}\]
Total productive land for one tonne of paper:
\[
\frac{1.8m^3}{1.99m^3} = 0.904 \text{ ha - yr}
\]

After conversion using the forest land equivalence factor,
\[
\text{ENERGYLAND } = 0.9106 \text{ [ha-yr/tonne]}
\]
\[
\text{FOREST LAND } = 0.904 \times 0.4569 = 0.413 \text{ [ha-yr/tonne]}
\]
\[
\text{TOTAL} = 1.32 \text{ [ha-yr/tonne]}
\]

Take as
1 ream = 2.3 kg
1 tonne = 1000 kg
1 tonne = 435 reams

Paper Reams (Bundles) = 500×12×2kg = 12,000kg
Newspapers = 50gm×100=5000gm = 5kg
EF = \[
\left(\frac{5000}{435}\right) \times 1.32 \Rightarrow EF = 1.52
\]

1.3.3 CALCULATION OF WASTE CONSUMPTION
Calculating Equation:
\[
\text{Paper waste } [\text{kg}] \times 0.0028 [\text{ha-yr/kg}] = \text{EF [ha-yr]}
\]
\[
\text{Glass waste } [\text{kg}] \times 0.001 [\text{ha-yr/kg}] = \text{EF [ha-yr]}
\]
\[
\text{Aluminum waste } [\text{kg}] \times 0.0094 [\text{ha-yr/kg}] = \text{EF [ha-yr]}
\]
\[
\text{Plastic waste } [\text{kg}] \times 0.0036 [\text{ha-yr/kg}] = \text{EF [ha-yr]}
\]
Derivation:
Ecological footprint of
Paper waste 2.8 ha-yr/tonne = 0.0028 ha-yr/kg
Glass waste 1.0 ha-yr/tonne = 0.001 ha-yr/kg
Aluminum waste 9.4 ha-yr/tonne = 0.0094 ha-yr/kg
Plastic waste 3.6 ha-yr/tonne = 0.0036 ha-yr/kg

Paper=7200kg×0.0028 =20.16
Glass=2232kg×0.001 =2.232
Al Cans=1086kg×0.0094 =10.2
Plastics=9722kg×0.0036 =34.99
Total EF =67.582

1.3.4 CALCULATION OF WATER CONSUMPTION
Calculating Equation:
Consumption (m$^3$) × 0.00008 [ha − yr/m$^3$]= EF [ha/yr]

Derivation:
UTM’s water consumption in m$^3$ can be obtained from Facilities Resources\textsuperscript{10}.

Ecological footprint for cold tap water is
0.08 m$^3$ha-yr/100 L (1 m$^3$ = 1000 L)
⇒ 1 \times 0.08 \left[ \frac{m^2 ha}{10000 m^3} \right] \times 1 \left[ \frac{ha}{10000 m^3} \right] = 0.00008[ha − yr/m^3]
⇒EF=46153.85×12×0.00008=44.308 (ha-yr)
⇒EF=44.308/(ha-yr)

1.3.5 CALCULATION OF ENERGY CONSUMPTION
Total mix of energy consumption as Footprint is given in Table A.3 of the Appendix.

Conversion factor equation:
\[ \text{Conversion factor} = \left( \text{fraction hydroelectric} \times (\text{footprint for hydroelectric}) + \right) \]
\[ \left( \text{fraction natural gas} \times (\text{footprint for natural gas}) + \right) \]
\[ \left( \text{fraction coal/oil} \times (\text{footprint for coal/oil}) \right) \]

(Green fleet, Diesel conversion factor, 2005)
⇒EF=717+94+754+120.78+10=1695.78
⇒EF=1695.78

1.3.6 CALCULATION OF FOSSIL FUEL CONSUMPTION(TRANSPORTATION GROUND VEHICLES)
Calculator Equation:
Consumption [L of diesel/yr] × 0.000867 [ha-yr/L] = EF [ha-yr]
Consumption [L of unleaded gasoline/yr] × 0.000774 [ha-yr/L] = EF [ha-yr]

Derivation:

**Diesel**

Diesel emissions\textsuperscript{2} 2.69 kg of CO$_2$/L
Uplift factor\textsuperscript{3} 1.45
CO$_2$ sequestration land\textsuperscript{4} 0.00019 ha-yr/km
Equivalence factor for forest land 0.4569

And then we get
\[2.69 \left( \frac{kg \ of \ CO_2}{L} \right) \times 1.45 \times 0.00019 \left[ ha - \frac{yr}{kg \ of \ CO_2} \right] \times 0.4569 = 0.0003386 \left[ ha - \frac{yr}{L} \right] \]

Unleaded gasoline
\[2.4 \ kg \ of \ CO_2/L \]
Uplift factor \[1.45\]
\[CO_2 \ sequestration \ land\]
\[0.00019 \ ha/yr/kg \ of \ CO_2 \]
Equivalence factor for forest land \[0.4569\]
\[2.4 \left( \frac{kg \ of \ CO_2}{L} \right) \times 1.45 \times 0.00019 \left[ ha - \frac{yr}{kg \ of \ CO_2} \right] \times 0.4569 = 0.000302 \left[ ha - \frac{yr}{L} \right] \]

Consumption \[24000L\ of \ diesel/yr\] \[0.0003386 \left[ ha - \frac{yr}{L} \right] = 8.126 \ EF \left[ ha - \frac{yr}{yr} \right] \]
Consumption \[6000L\ of \ unleaded \ gasoline/yr\] \[0.000302 \left[ ha - \frac{yr}{L} \right] = 1.812 \ EF \left[ ha - \frac{yr}{yr} \right] \]
TOTAL EF=9.938

1.3.7 CALCULATION OF CAR-DROP OFFS
Calculating Equation:
\[\text{Distance of car} - \ km \times 0.12 \left( \frac{L}{\text{car} - \ km} \right) \times 2.4 \left( \frac{kg \ of \ CO_2}{L} \right) \times 1.45 \times 0.00019 \left[ \frac{ha - \ yr}{kg \ of \ CO_2} \right] \times 0.4569 \times 5\]

Total distance travelled is given in Table A.4 of Appendix
Average fuel consumption \[8\]= 0.12 L/car-km
Uplift factor \[10\]= 1.45
\[CO_2 \ sequestration \ land\]
\[0.00019 \ ha/yr/kg \ of \ CO_2 \]
Equivalence factor for forest land \[0.4569\]
Ten passenger car equivalence factor = 5

Car Km Travel= (130\times2\times250)+35,000=100,000Km
\[\Rightarrow \ EF \left( \frac{ha - yr}{km} \right) = 100,000 \times 0.00018126 = 18.13\]
\[\Rightarrow \ EF=18.13\]

1.3.8 CALCULATION OF BUILT UP LAND AREA WITHIN CAMPUS
Calculator Equation:
\[\text{Consumption} \left[ \frac{m^2}{yr} \right] \times 0.000006 \left[ \frac{ha}{m^2} \right] = EF \left[ ha - yr \right] \]

Derivation:
Campus built-up land includes the area of buildings, parking lots, road space, and all impermeable surfaces.
Equivalence factor for built-up land = 0.060
\[\text{Consumption} \left[ \frac{m^2}{yr} \right] \times 0.0001 \left[ \frac{ha}{m^2} \right] \times 0.060 = 0.000006 \left[ ha - \frac{yr}{m^2} \right] \]
\[\Rightarrow \ EF = 40 \text{hactares} = 40 \times 10000 = 400,000 \text{km}^2 \]
\[\Rightarrow \ EF = 400,000 \times 0.000006 = 2.4 \left( \frac{ha - yr}{yr} \right) \]
\[\Rightarrow \ EF = 2.4\]

Sum of Total of All EF=1839.65 Ha-Yr=4599.145acres
(Kitzes, J., Peller, A., Goldfinger, S., & Wackernagel, M. 2007)

III. RESULTS

[10] Wackernagel and Rees estimate that the equivalent of 15% of the fuel energy use is needed to manufacture and maintain a vehicle with an extra 30% for the construction and maintenance of the road infrastructure (p.85, Sharing Nature’s Interest).
The Total Ecological Footprint of the University Campus Area is calculated by finding out the individual
categories of footprint as Hydroprint, Waste print, Electricity print, Fossil fuel print, Paper print, Built-Up Land
Area print. This helps to find out Per Capita Footprint in Acres or hectares-year. The sum total of all the
Ecological footprints is 4599.145 acres. The Per capita university footprint is 0.34 as given in Table A.5 of the
Appendix. The Campus Footprint Component ha-yr is depicted in Fig.A.1 while percentage component is
depicted in Fig.A.2

3.1 SUSTAINABILITY OF UNIVERSITY
The Footprint comparison for campus footprint per person and recommended footprint is given in Table A.6
and shown in Fig.A.3 of the Appendix.

3.1.1 SUSTAINABILITY ANALYSIS
The university land space is 255 acres and the hydrospace is 84 acres which gives the value of 339
acres for Ideal sustainability (Venetoulis, J. (2001). Strong sustainability is 1.6 acres per capita on world average
and weak sustainability is 3.4 acres per capita on world average. This is given in Table A.7 of the Appendix and
sustainability of Debre Berhan University is shown in Fig.A.4

IV. DISCUSSION
The Ecological footprints of various resource consumptive materials in the university campus area like
Hydroprint, Waste print, Electricity print, Fossil fuel print, Paper print, Built up Land area print are calculated
in the result section and the total Ecological footprint of the university area is evaluated which is 1839.65hac or
4599.145 acres.

(1 hectares =2.5 acres). Since this footprint score of the university is 18 times the university area of 255
acres, the per capita university footprint space is 0.34 acres. In comparison to the available footprint space per
person in the country 1.0123 acres (Monfreda, C., Wackernagel, M., &Deumling, D. 2004), this value of per
capita university footprint is three times short. While if we compare this score of 0.34 acres with the world
average footprint per capita of 5 acres, then it is almost 15 times short of the recommended space. This score is
used to evaluate and analyse the sustainability of the university on ecological basis. The criteria followed is the
quantitative evaluation of ecological footprint and sustainability of the score which is used for scoring on
qualitative terms. The Ideal Sustainability is the sum total of university area (255) and hydrospace (84) which is
339 acres. Strong sustainability is the world average per capita of 1.6 acres which in university acres is 21,660
(1.6*13,538) while the Weak Sustainability is 3.4 acres which in university acres is 46,029 (3.4*13,538). To be
ideally sustainable the university footprint per capita should be less than or equal to the sum total of 339 acres.
Since the campus ecological footprint space is 4599.145 acres which is five times less than the required Ideal
sustainability space, so it proves the Strong sustainability of the university space. However, in this research
paper only few footprint spaces of the campus are included while other factors like pavements are not included
which might change the sustainability criteria.

V. CONCLUSIONS
The ecological footprint analysis reveals the consumption pattern of natural resources with minimum
impacts on the nature which seems to be impossible by using conventional approaches or environmental
techniques. The consumption gap is widely viewed by using the current state of technology. This helps in the
community awareness and decision making process for the university management.

APPENDIX

<table>
<thead>
<tr>
<th>Table A.1: Equivalence Factors for Ecological Footprint Consumption Per Capita Ethiopia-2013</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land Category</strong></td>
</tr>
<tr>
<td>Fossil energy (carbon)</td>
</tr>
<tr>
<td>Built-up area</td>
</tr>
<tr>
<td>Crop land</td>
</tr>
<tr>
<td>Fishing ground</td>
</tr>
<tr>
<td>Forest, including deforestation</td>
</tr>
<tr>
<td>Grazing Land</td>
</tr>
</tbody>
</table>
### Table A.2 Total Energy Supply-2014 (International Energy Agency)

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>% of Energy Mix</th>
<th>Energy of GJ out of 25 GJ</th>
<th>GWh (1 GWh = 3600 GJ)</th>
<th>Ha-yr per GWh</th>
<th>Land (ha-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.6</td>
<td>0.4</td>
<td>0.000111</td>
<td>717</td>
<td>0.07969</td>
</tr>
<tr>
<td>Renewable</td>
<td>0.1</td>
<td>0.025</td>
<td>0.0000069</td>
<td>120.78</td>
<td>0.0008334</td>
</tr>
<tr>
<td>Biomass</td>
<td>92.2</td>
<td>23.05</td>
<td>0.0064</td>
<td>10</td>
<td>0.064</td>
</tr>
<tr>
<td>Natural gas</td>
<td>6</td>
<td>1.5</td>
<td>0.0004167</td>
<td>94</td>
<td>0.03917</td>
</tr>
<tr>
<td>Coal/oil</td>
<td>6.1</td>
<td>1.525</td>
<td>0.000424</td>
<td>754</td>
<td>0.3197</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.9106</td>
</tr>
</tbody>
</table>

Total Land for 1 tonne: 0.9106

### Table A.3 Total Electricity mix consumption as Energy Footprint

<table>
<thead>
<tr>
<th>Electricity Type</th>
<th>Footprint (ha-yr/GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydroelectric</td>
<td>717</td>
</tr>
<tr>
<td>Natural gas</td>
<td>94</td>
</tr>
<tr>
<td>Coal/oil</td>
<td>754</td>
</tr>
<tr>
<td>Renewable</td>
<td>120.78</td>
</tr>
<tr>
<td>Biomass</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table A.4 Total distance travelled in Km for Transport Footprint

<table>
<thead>
<tr>
<th>Distance category</th>
<th>Distance of 1 round trip (estimate) [km]</th>
<th>Total distance in 1 year (140 days) [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2 km</td>
<td>4</td>
<td>560</td>
</tr>
<tr>
<td>2-5 km</td>
<td>10</td>
<td>1400</td>
</tr>
<tr>
<td>5-10 km</td>
<td>20</td>
<td>2800</td>
</tr>
<tr>
<td>&gt; 10 km</td>
<td>30</td>
<td>4200</td>
</tr>
</tbody>
</table>

### Table A.5 Ecological Footprint Per Capita of University Campus Area

<table>
<thead>
<tr>
<th>Footprint Component (ha-yr)</th>
<th>Percentage of total</th>
<th>Per capita footprint (ha-yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro print</td>
<td>44.308</td>
<td>2.41</td>
</tr>
<tr>
<td>Waste print</td>
<td>67.582</td>
<td>3.67</td>
</tr>
<tr>
<td>Electricity print</td>
<td>1695.78</td>
<td>92.17</td>
</tr>
<tr>
<td>Fossil fuel print</td>
<td>28.068</td>
<td>1.52</td>
</tr>
<tr>
<td>Paper print</td>
<td>1.52</td>
<td>0.083</td>
</tr>
<tr>
<td>Built up Land area print</td>
<td>2.4</td>
<td>0.13</td>
</tr>
<tr>
<td>Total</td>
<td>1839.85ha-yr/4599.145 acres</td>
<td>100.00</td>
</tr>
</tbody>
</table>

### Table A.6 Comparisons of Footprint per capita

<table>
<thead>
<tr>
<th>Campus Footprint (acres)</th>
<th>Recommended footprint (acres)</th>
<th>Footprint space per person in Ethiopia (acres)</th>
<th>World Footprint space per person (acres)</th>
<th>Campus Footprint per person (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4599.145</td>
<td>21,660</td>
<td>1.012</td>
<td>5</td>
<td>0.34</td>
</tr>
</tbody>
</table>

### Table A.7 Sustainability Analysis in Acres of Ecological Footprint

<table>
<thead>
<tr>
<th>Ideal Sustainability (acres)</th>
<th>Strong Sustainability (acres)</th>
<th>Weak Sustainability (acres)</th>
<th>Campus Footprint (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>339</td>
<td>21,660</td>
<td>46,029</td>
<td>4599.145</td>
</tr>
</tbody>
</table>

Figures

Fig. A.1

**Footprint Component (ha-yr)**

- Built up Land area print: 2.4
- Paper print: 1.52
- Fossil fuel print: 28.068
- Electricity print: 1695.78
- Waste print: 67.582
- Hydro print: 44.308

<table>
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<tr>
<th>Component</th>
<th>Value</th>
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</tr>
<tr>
<td>Built up Land area print</td>
<td>2.4</td>
</tr>
</tbody>
</table>

Fig. A.2

**Percentage of Footprint component**

- Hydro print: 2.41%
- Waste print: 3.67%
- Electricity print: 1.52%
- Fossil fuel print: 0.083%
- Paper print: 0.13%
- Built up Land area print: 92.17%
REFERENCES


