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Life Cycle Ecological Footprint Assessment in a Residential Project

A Case of Tirurangadi Region in Malappuram – Kerala

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Abstract: We are living on a planet of uncontrolled growth and exhausting resources. One of the many reasons behind this is unexpected consumption and development. There is a need to find a way to balance human consumption and nature's limited productivity. This study investigates the ecological impacts across each of the development stages of a household unit, based on the theory of 'Ecological Footprint'. To evaluate the environmental impact of the building, a method has been developed to assess the ecological footprint of the building during its entire life cycle, as to calculate its impact on the utilization of resources (energy, water, building materials, manpower, etc.) and therefore the assimilation of waste during the entire life cycle of the building. This is done to encourage and inform ways that can be included in the building sector and have architects and related professionals involved in all the life cycle stages of a building by assessing and quantifying the environmental impacts. This will help in self-evaluation at the initial design stages of the residential project. The study is mainly based on the life cycle ecological footprint ($LCEF_{total}$) of household units in an urban context. The $LCEF_{total}$ of household units in the Tirurangadi Municipality area is calculated to quantify the consumption during its life cycle and compare it with the existing biocapacity. The results from the study for the predominant household units within the selected urban region for the year 2019-2020 show that the sustainability of an urban household has a significant Ecological footprint thought out its lifecycle. Therefore, the house designers, planners, and developers ought to make decisions regarding, construction, operation, maintenance, and demolition methods to reduce unnecessary waste of energy and resources. Conclusions of the research and recommends that LCEF can be used as an effective environmental management tool to assess the sustainability issues of urban areas. The findings of this research focus on the societal need to keep the cities livable and sustainable.

***Index Terms* - Sustainable Development; Planning; Environmental; Physical; Ecological; Carrying capacity; Assessment; Built environment; Whole Life Cycle Ecological footprint; Malappuram; Residential and Environment stability; Household.**

I. INTRODUCTION

Today, the global population on it are using more of the earth's resources than it can provide. Every new person is an added consumer, contributing to that demand. Some of us take far more than others and there are many steps we must take to make our consumption sustainable - adding fewer new consumers everywhere is one of them [1].It is well known that many of the Earth's resources are finite. We are presently dependent on fossil fuels, iron, and alternative metals, minerals, and even such basic commodities as sand to stay the modern world ticking over.

Hence increase in population makes those resources run out faster. However, our demands are so great that according to the Global Footprint Network, we are now using those resources twice the rate that the Earth can renew them. That rate has expanded persistently since the 1970s and, unless things change, we will require three Earths to supply our necessities by 2050. There is a need for more balanced global system, in which resources are distributed more equitably, instead of consumption is essential. Whatever form that takes, in order to ensure that there is enough to meet everyone's right to a decent standard of living, the richest must consume more sustainably.

Yan Zhao [2] is the first scholar to use an ecological footprint and energy analysis to evaluate a building. Their article calculates the ecological footprint of the construction stage of a house. Zhe Yan [3] determined that the decrease of the ecological footprint through five primary angles; land saving, energy saving, water saving, material saving, and protection of the environment. This study is significant, as the huge enhancement in infrastructure and its life cycle resource consumption will be needed in near future to improve the current household development scenario in India. Indian resource demands have already surpassed the obtainable bio-capacity of the country.

This study is a step in overall estimation of natural resource demand of the regional household sector and laying out a policy framework to follow.

Abbreviations

EF	Ecological Footprint
EF_{avg}	Average annual Ecological Footprint
$EF_{avg/resident}$	Average annual Ecological Footprint per resident
C&D	Construction and demolition
CPWD	Central public work department
gha	Global hectare
e_i	Equivalence factor
LCA	Life cycle analysis
LCE	Life cycle energy
$LCEF_{total}$	Life cycle ecological footprint
$LCEF_{e\&m}$	Life cycle ecological footprint of energy and material consumption
$LCEF_{w}$	Life cycle ecological footprint of water consumption
$LCEF_{t}$	Life cycle ecological footprint of transportation
$LCEF_{we}$	Life cycle ecological footprint of C&D waste disposal
$LCEF_{m}$	Life cycle ecological footprint of manpower
$LCEF_{built-up}$	Life cycle ecological footprint of built-up land consumption

Need for the study

i. According to WWF, during the last thirty years, consumption of natural resources has increased 40%, while earth's natural wealth in biodiversity has decreased 30% [4]. To feed and fuel our 21st century lifestyles, we are overusing the Earth's biocapacity by at least 56% [5].
ii. A large percentage of the population in India is still struggling to meet their basic needs and as such most do not care about long-term needs and impacts.
iii. By 2030, more urban than rural dwellers, metropolitan India has a serious lack of housing, yet Indian urban communities have numerous vacant houses [6].
iv. Even though, when population size declines, the quantity of family units has expanded significantly, household dynamics influence per capita consumption, therefore impacts the biodiversity [7].
v. Drawback in the existing assessment tools. Lack of policies and frameworks for resource consumption in development of household sector.

Research questions

i. Does designing, the production, operation and demolition phases of a single family household unit under residential sector have significant ecological footprint and do they collectively generate environmental pressure?
ii. Why is it important that we need to measure the ecological carrying capacity of a given site and quantity of consumption of natural resources, used for the life cycle of single household unit for a sustainable development?

Aim

To access the biocapacity of a region in terms of built-environment development for a sustainable future by analyzing the whole life cycle ecological footprint of a selected study.

Objectives

i. Study about carrying capacity and its concepts.
ii. Study the existing tools for assessment of carrying capacity of a built environment. Understanding the process/components of Ecological Footprint Analysis and Life Cycle Ecological Footprint as a tool to assess and measure consumption and environmental impact due design, production, operation and demolition of a building.
iii. Study the environmental impact of all stages of urban household unit at regional, city and local scales; implemented methods for reduction of environmental impact; existing policies regarding sustainable housing development.
iv. Selection of study area and implementation of Ecological Footprint calculator to measure Carrying Capacity of study area.
v. Selection of sustainably suitable residential area within the region and implementation of Whole Life Cycle Ecological Footprint to measure the ecological footprint of a selected cluster type of residential household unit, by quantifying consumption and comparing with biocapacity households in the selected study area.
vi. Formation of guidelines and strategies for reducing the whole life-cycle Ecological footprint for household sector development in the selected study area.

Scope of research

To have architects and related professionals involved in all the life cycle stages of a building by assessing and quantifying the environmental impacts. This will help in self-evaluation at the initial design stages of the residential project.

II. BACKGROUND STUDY

Literature review of related research papers

The related research papers are an attempt made to explore the tool Ecological Footprint Analysis of a whole life cycle of a building. The study also analyses the ecological footprint calculation method, the scope of the tool as an impact assessment tool in India, and measures to reduce the ecological footprint, expanding the idea of ecological capacity to architecture. Ming Liu et al. [8] conducted a study based on the theory of ecological footprint by comparing the whole life-cycle ecological footprint between the northern rural house with various energy-saving measures and the urban multi-layer residence with only external wall thermal-insulation as the energy-saving measure. By combining whole life-cycle assessment and ecological footprint theory, they were able to analyze and quantify the effect of the rural house and the multi-layer residence on environment. Another study conducted by Dilawar Husain and R. Prakash [9] to calculated the $LCEF_{total}$ for an academic building located in India. Therefore investigating the $LCEF_{total}$ of a building using the component approach, the building can be compared and differentiated based on their Ecological Footprint.

Inference

After reviewing all the literature based on this topic there are study based on carrying capacity of an area using different methods conducted at different regions depending on the area (building level, ward level and urban level) the knowledge gap exist at the neighborhood level. Several international conferences and reports stresses its importance, since the world’s population has already surpassed the carrying capacity of the Earth, and in efforts to improve people's welfare there is a tremendous increase per capita footprint. The number of family units expanded considerably, even when population size declined. Rural residents are no longer satisfied with the traditional way of life and urgently need beautiful environments and full-featured new house patterns, resulting in significant resources being consumed each year in housing construction and operation as the rural inhabitants' shifts to urban areas at a rapid pace. Therefore, only by accurately analyzing and evaluating the increase of a single family household pressure on the natural environment to enable the development of design and technical standards that take effective measures, such as residential design, construction, operation and demolition stages, into consideration be realized.

If we establish criteria that are based on our understanding of environmental capacity, we will begin to develop a building stock that is sustainable. To do this, we must define the relationship between the environmental impacts caused and their causes during the production and use of the building. This is not done in the traditional built-in environmental impact assessment methods. LCA of building regularly did exclude impacts because of labour/manpower involved. The studies conducted using this didn't assess the impacts of resource consumption such as water, manpower, waste absorption, and built-up land on the environment.

These resources have the significant impact on our earth and should not be neglected. Ecological Footprint and Life Cycle Analysis has its own strengths and weaknesses, combing both can be integrated. Life Cycle Assessment framework can be used to generate efficient results in the Ecological Footprint Assessment method. Current research on a building’s ecological footprint is bound to examining the ecological footprint created during the development time frame into the investigation model for estimation. There is an absence of examination with respect to the total ecological footprint on the whole life-cycle of a structure for the design stage, construction stage, operation stage, and demolition stage in related research.

This study is a step in the overall estimation of natural resource demand of the Indian household sector. Such a study may also be helpful in exploring the possibilities of reducing EF of the development and the rapid increase of residential household sector of the country. Ecological footprint theory is an important method of measuring sustainability and has been widely applied in many fields to evaluate concepts such as economic systems, energy use, tourism, dietary structure, etc., but it is not yet mature in the field of architectural design.

This study is significant, as the huge enhancement in infrastructure will be needed in near future to improve current residential sector development scenario in India. According to Global Footprint Network, the total Ecological Footprint per capita is 0.8 gha/person [10]. Indian resource demands have already surpassed the available bio-capacity of the country.

III. STUDY AREA

Criteria for selection of study area

i. Highest population density in Kerala.
ii. Highest urbanized area in Kerala.
iii. Overlapping both of the above features.
iv. Selecting a district.
v. Highest population density area within the district.
vi. Highest urbanized area within the district.
vii. Selecting a settlement.

Malappuram

Malappuram, is the No. 1 among the 10 fastest growing cities in the world, in terms of population, as indicated by the most recent rankings by the Economist Intelligence Unit (EIU, 2020). The analysis has been gathered based on the information given by the United Nation's Population Division. Reason is for the most part due to high paces of change from rural to urban areas. The apparent limits of specific urban areas, known as urban agglomeration that incorporates thickly developed zones outside the authority civil limit, is extending quick (Nijeesh, 2020). Northern districts like Kozhikode, Kannur, Malappuram and Kasaragod have reported highest percentage point increase in the proportion of good condition houses from year 2001 to 2011. Malappuram District has the largest overseas population in Kerala. At least one member in one family is in abroad.

It is a general trend in the district is that to make highly expansive homes and villas for their comfort stay and shopping complexes and other amenities. Hence all construction, construction materials including hollow bricks, metals, pipes, tiles etc. has very high demand in the district [11].

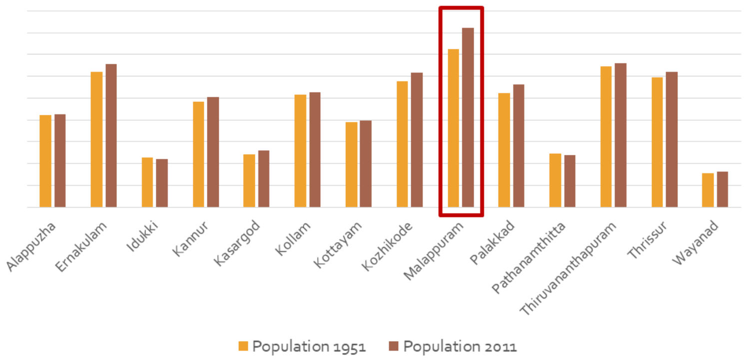

Figure 1: District wise decadal growth rate-Kerala. Source: Census 2011

Malappuram is the fasting growing district in the state, and has shown tremendous growth rate in the last decade. According to 2011 census urban area is present in all taluks and Tirurangadi (6,52,326) is the most urbanized taluk. The following graphs has been generated on bases Census 2011 details to select the village/town to study within Tirurangadi taluk.

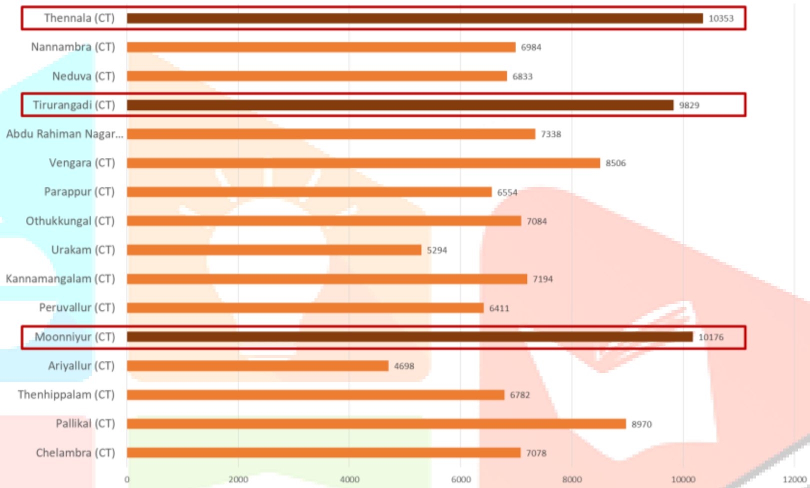

Figure 2: Number of Households within Tirurangadi Taluk

There are three villages (Thennala, Tirurangadi, Moonniyur) with highest number of households compared to others. Tirurangadi has the highest population density compared to other villages/towns. Tirurangadi has the highest ratio between households and village area compared to other villages/towns with an average area of 5.54 hectares per household.

Ecological footprint of Tirurangadi

Table 1: Average Ecological Footprint of the selected samples in Tirurangadi (Source: Author)

Number of Earths required to live	3.5	
By Land Type		
Built-up land	0.26	gha
Forest products	0.8	gha
Cropland	1.42	gha
Grazing land	0.1	gha
Fishing grounds	0.54	gha
Carbon Footprint	3.24	gha
By Consumption Category		
Food	1.72	gha
Shelter	0.8	gha
Mobility	1.1	gha
Goods	1.3	gha
Services	1.1	gha
Ecological footprint	6	gha
Carbon Footprint (CO_2 emissions in tonnes/year)	9.42	tonnes/year
Carbon Footprint (% of your total Ecological Footprint)	53.2	%

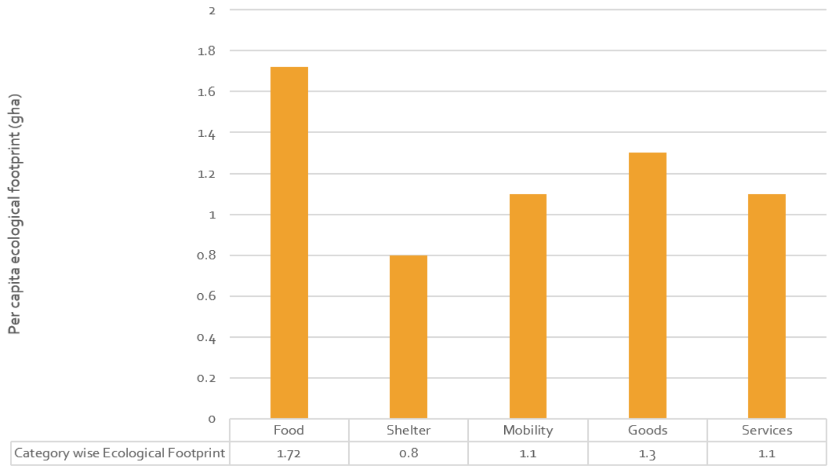

Figure 3: Category wise ecological footprint in Tirurangadi (Source: Author)

From the above figure for all the residents, the food footprint goes to the maximum followed by goods and services, mobility and shelter footprint.

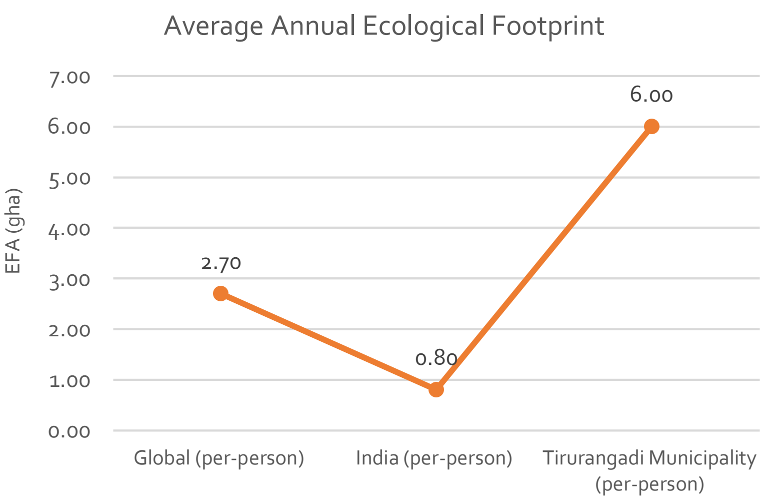

Figure 4: Comparison between average Ecological Footprint of Global National and Regional (per person)

Results and findings from the Ecological Footprint Analysis of Tirurangadi Municipality:

i. From the studies, it is revealed that the consumption rate (EF = 6 gha) of the neighbourhood is very high and it is far exceeding the national average (0.8 gha).
ii. Its consumption exceeds the available bio productive space per person in the world.
iii. According to Global footprint calculator if everyone lived like this we would need 3.5 earths to sustain our life.
iv. Due to the foreign influence and statues increase in the shelter footprint is visible and outsourced eating preferences are adopted.
v. Ratio between the Ground Coverage area of house and Plot area

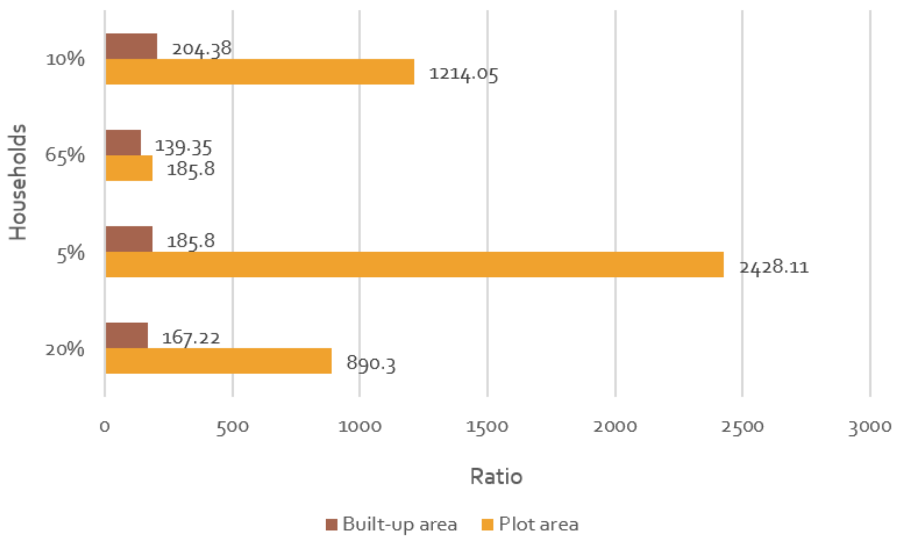

Figure 5: Ratio b/w House Ground coverage and Plot area in Tirurangadi (Source: Author)

From the above figures and table it is understood that 65% of residents in Tirurangadi municipality has household ground coverage area 75% of their plot area.

IV. RESEARCH METHODOLOGY FRAMEWORK

Methodology

In this paper, the EF indicator has been integrated with the LCA approach for assessment of the impact of a building project on the biosphere that determines the $LCEF_{total}$ of a structure dependent on natural resource consumption, GHG emissions and waste absorption. LCA of building project is characterized as to research and quantify the ecological consequences during their life, from the extraction of raw materials, material production, construction phase, use and maintains phase, materials and C&D waste transportation, and demolition phase. The life cycle of a building is associated with resource consumption (material, fuel, electricity, water, etc.), transportation, manpower, physical land use for building construction and C&D waste disposal (landfill or recycling and reuse, etc.). All the above parameters are converted into the equivalent productive land needed to produce or absorb their impacts in the form of CO2 absorption land, forestland, cropland and built-up land. $LCEF_{total}$ contains all phases of the building's life: implementation and construction phase, operation and maintenance phase and demolition phase.

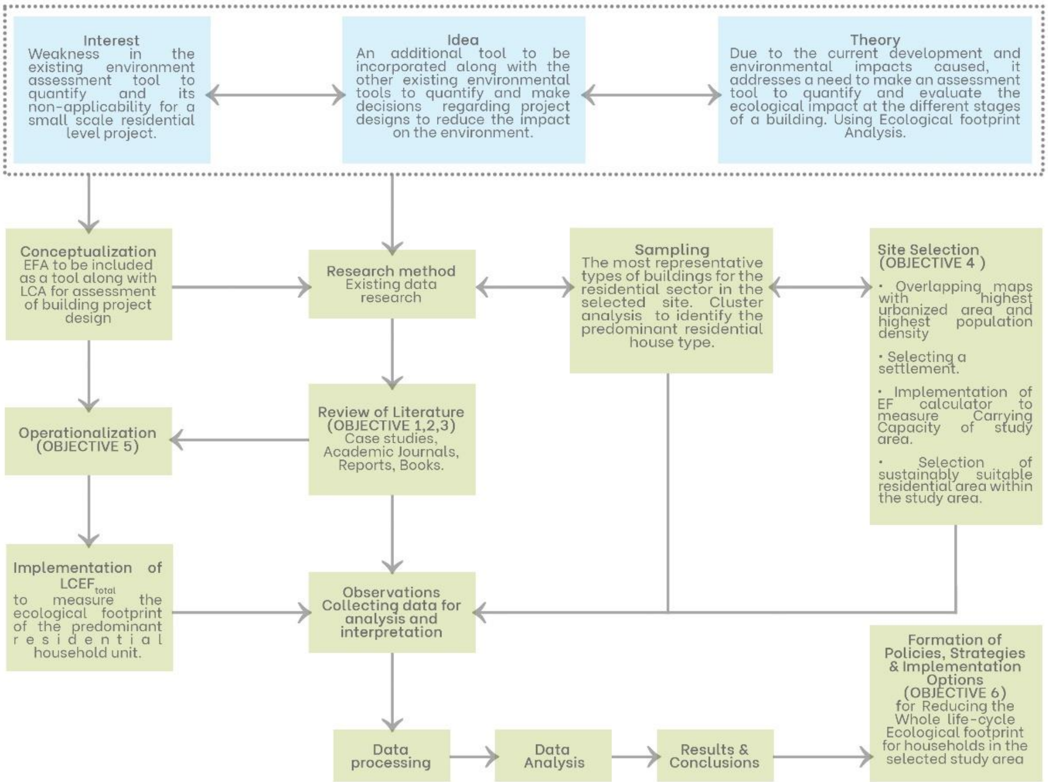

Figure 6: Research framework Flow-chart

The study is conducted

i. to compute EF of residential buildings of study area;
ii. to evaluate the level of natural resource consumption against available local biocapacity and
iii. to explore the relationship between Ecological Footprint along with family size, ground coverage area, and plot area.

Selection of sample residences

The chosen neighbourhood area contains detached residential structures.
GIS mapping was used for the following:

i. To identify the region with highest density of household number and residential suitability analysis of the area (i.e., infrastructure support and transport access facilities within 500 m distance).
ii. Cluster analysis for grouping the sampled residences on bases of no. of dwelling units, household size, number of floors, % of ground coverage, housing built- up area respectively.
iii. Distances from the source of materials transported to the site, the quantity of fuel consumed was determined from distances travelled, and average fuel utilization of the trucks were calculated in the GIS software.

Parameters for cluster analysis

i. No. of Dwelling units
ii. Household size
iii. Number of floors.
iv. Ground coverage Area/Plot area (%)
v. Housing Built- up Area (m^2)

As shown in Figure 7 below, by calculating the ecological carrying capacity and comparing it to the ecological footprint in the design, construction, operation, demolition, and recycle stages, the pressing factor of the structure's life-cycle on nature can be obtained. Thus, the design strategies that increase the biological excess in each stage and add to sustainability can be broken down throughout the span of the structure's whole life.

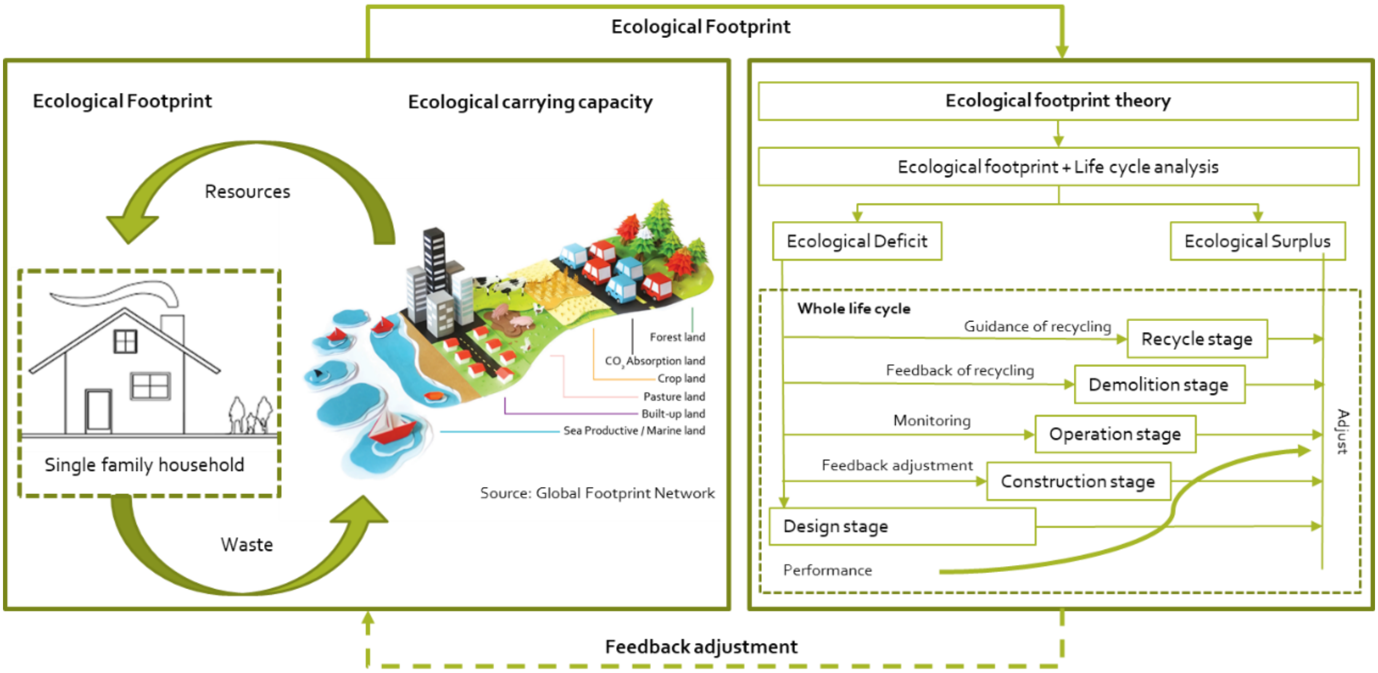

Figure 7: Research thought of the paper

$LCEF_{total}$ contains all stages of the building's life: implementation, construction phase, operation and maintenance phase and finally demolition phase.The principle of evaluating the $LCEF_{total}$ of a building is shown in Figure 7. It is utilized to successfully analyse the effect of building project on the earth and determined with Eq. (1):

$$LCEF_{total} = LCEF_{e\&m} + LCEF_{w} + LCEF_{t} + LCEF_{we} + LCEF_{m} + LCEF_{built\text{-}up} \qquad (1)$$

where, $LCEF_{e\&m}$, $LCEF_{w}$, $LCEF_{t}$, $LCEF_{we}$, $LCEF_{m}$ and $LCEF_{built\text{-}up}$ represent the life cycle ecological footprint of energy and material consumption, water consumption, transportation, waste generation, manpower, and built-up land consumption of the building, respectively.

V. DATA COLLECTION

Location

Tirurangadi is a municipal town in Malappuram district of Kerala, India.

Table 2: Tirurangadi Municipality

Source: https://tirurangadimunicipality.lsgkerala.gov.in/en/

Country	India
State	Kerala
District	Malappuram
Area total	17.73 km^2
Elevation	10 m (30 ft)
Population (2011)	
Total	56,632
Density	3,200/km^2 (8,300/sq mi)
Official Languages	Malayalam, English

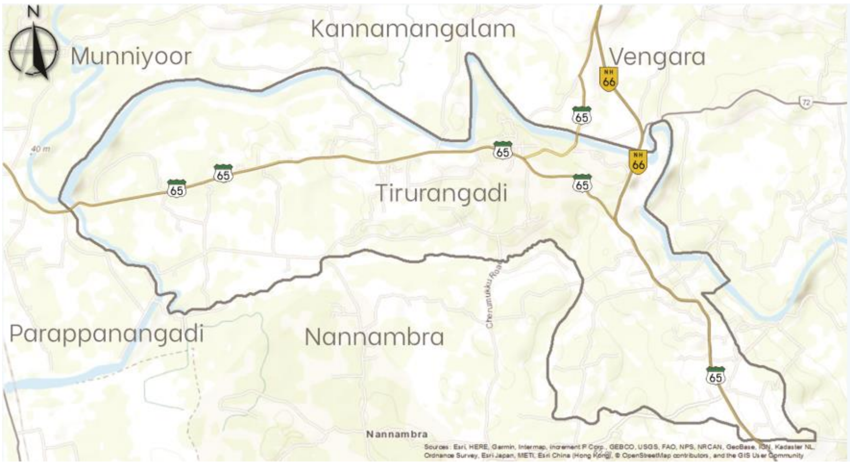

Figure 8: Location Map of Tirurangadi Municipality
Source: Google Earth

Tirurangadi Block, the area of the present study, lies in the north-western part of Malappuram District. The area is bounded by the Arabian Sea in the west, Chaliyar River and Chelembra Panchayat, a part of Kondotty Block in the North, Vengara Block on the East, and Tanur in the South.

Parameters to find suitability for residents:

Table 3: Parameters for identifying area suitable residential purpose

Infrastructure	Education facilities
	Heath care facilities
	Provision infrastructure
	Recreation facilities
	Socio-cultural facilities
	Sports facilities
	Distribution services
Public Transport	Bus stand
	Auto/taxi stand
Road Access	Access to LSGI roads
	Access to NH and SH roads

Figure 9: Suitability analysis for Residential purpose (Source: ArcGIS)

Figure 10: 400 m radius - Most suitable for Residential Purpose
Source: Google Earth

Cluster analysis

Table 4: Cluster Analysis Parameters - Household units

Building parameters	**Specifications**		
Cluster type	A	B	C
Plot area	≈ 150 m²	≈ 200 m²	≈ 300 m²
Residential floors	GF / GF+1	GF+1	GF+2
Total Ground coverage	Below 50 m²	120 - 250 m²	Above 50 - 100 m²
Total Built up area	50 m²	≈ 180 m²	≈190 m²
No. of Dwelling units	2	3	5
Household size	< 5	6-8	> 9
Built-up Area / Plot area (%)	Below 18%	60%	25%
Number of Units (468 total)	190	252	26
Number of Units (%)	41%	54%	6%

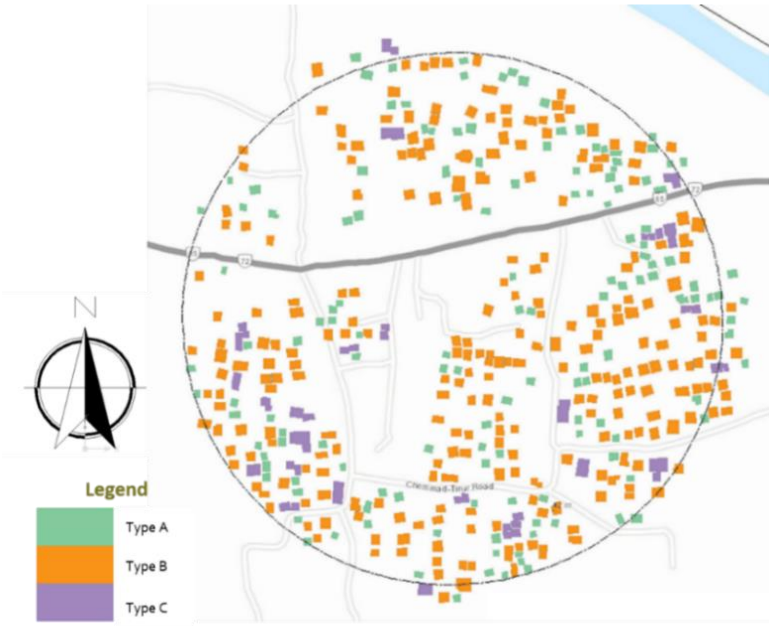

Figure 11: Cluster analysis - Household units
Source ArcGIS

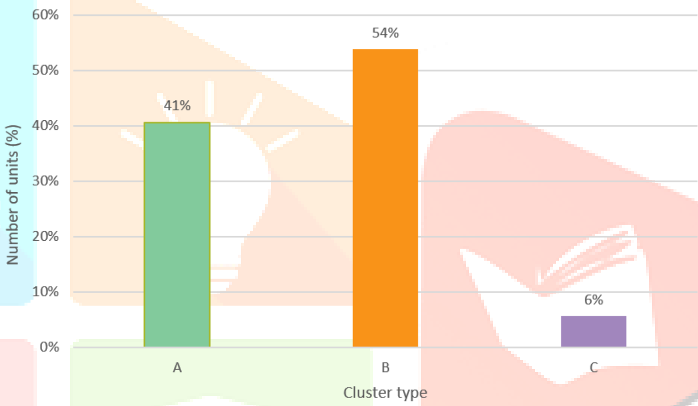

Figure 12: Cluster analysis Summary

It is observed from Cluster analysis – Cluster type B – (252 number of household samples) with similar characteristics. Hence, conducting Life Cycle Ecological Footprint ($LCEF_{total}$) analysis for all households from cluster B (located within 400 m radius) will generate similar results.

Case study - Residential household Cluster Type B

Description of the case study (Household Cluster Type B)

Life cycle ecological footprint of a household unit has been calculated as a way to measure progress towards a broad goal of increasing the sustainability of the single household unit development in urban areas. The household unit typology of this study is a most predominant type of household building for the residential area in the selected region of Tirurangadi region in Malappuram, Kerala, India. Area of the site is approx. 200 m², the house has a ground coverage area of about 60% with one floor above ground. The household size is 6 – 8, with 3 dwelling units.

Table 5: Details of material consumption, machinery used and all activities in the Household (Cluster Type B)

Sr.no.	Materials	Unit	Consumption	Average transported distance (km)	Emission factor ($kgCO_2/kg$)	Emission factor ($kgCO_2$)	EF/item (gha/unit)	EF (gha)
1	Stone masonary	m^3	6465.428375	50	0.056	362063.989	0.000210955	1.363914443
2	Cement	kg	39269.664	50	0.675	26507.0232	0.000083	0.003259382
3	Fine and coarse sand	ton	1589.49	85	-	-	-	-
4	Aggregates	ton	1184.33	50	0.0048	5157.149294	0.00001	0.010744061
5	Steel	ton	7791.64	500	2.85	20145102.19	0.00066	4.665181559
6	Wood	m^3	3.139847593	300	3.23	10141.70773	0.000023	7.22165E-05
7	Glass (common)	m^3	0.04639	25	0.86	39.8954	0.0026	0.000120614
8	Ceramic tile	m^3	2.07408399	1500	0.74	1534.822153	0.0035	0.007259294
9	PVC pipe	ton	0.147235722	25	2.56	341.9392005	0.00085	0.000113535
10	Paint	ton	0.345083	500	0.36 $kgCO_2/m^3$	0.0480852	0.00012	3.75665E-05
11	Electricity	kWh	6192000	-	8.2 tCO_2/MWh	50774.4	0.00039	2414.88
12	Labour	Working days (8h)	4720	10	-	-	0.0009	4.248
13	Water	m^3	29,789.03	-	-	-	0.000000049	0.001459662
14	Electrical vibrator	m^3 (concrete)	0.36194 kWh	-	8.2 tCO_2/MWh	0.002967908	0.00016	5.79104E-05
15	Bus	km-person	152.32 kg of diesel	-	3.17 $kgCO_2$/kg of fuel	482.8544	0.0000042	0.000639744
16	Heavy-duty truck	km-kg	90.485 kg of diesel	-	3.17 $kgCO_2$/kg of fuel	286.83745	0.00000204	0.000184589
17	Concrete mixer	m^3 (concrete)	20 kg of diesel	-	3.17 $kgCO_2$/kg of fuel	63.4	0.00078	0.0156

Life Cycle Ecological Footprint of Energy and Materials Consumption ($LCEF_{e\&m}$):

The $LCEF_{e\&m}$ of a building is estimated by summing up the energy & materials expenditure for each phase of the building life. The building's $LCEF_{e\&m}$ is calculated using the following relations:

$$\mathrm{LCEF}_{e\&m} = \{L_{CO_2}.((1|-S_{oc})/A_f)\} \cdot e_{CO_2\text{land}} + \left\{\sum \frac{C_{wi}}{Y_{wi}}\right\} \cdot e_{\text{forest}} \tag{2}$$

where, L_{CO2} is total life cycle emission of a building. The total life cycle emission during the lifespan of a building due to direct energy used and embodied material energy is calculated using the following relations:

$$L_{CO2} = M_{CO2} + \sum(E_c \cdot \lambda_i) + (E_o \cdot L_b) \cdot \lambda_{\text{electricity}} + \sum(E_d \cdot \lambda_i) \tag{3}$$

Life Cycle Ecological Footprint of Transportation ($LCEF_t$):

The $LCEF_t$ consists of three stages

(a) raw material transportation from factory to construction site,

(b) manpower transportation from their houses to project site,

(c) C&D waste disposal from the site to land fill area.

The life cycle EF of transportation is calculated with Eq. (4):

$$\mathrm{LCEF}_t = \left\{\left(\sum \frac{C_{mi} \cdot D_{mi}}{T_c} + \sum \frac{C_{wj} \cdot D_{wj}}{T_c}\right) \cdot E_{\text{truck}} + \sum \frac{M_k \cdot D_{mk}}{T_b} \cdot E_{\text{bus}}\right\} \cdot \lambda_{\text{diesel}} \cdot \left(\frac{1-S_{oc}}{A_f}\right) \cdot e_{CO_2\text{land}} \tag{4}$$

Life Cycle Ecological Footprint of Manpower ($LCEF_m$):

To determine the $LCEF_m$, food consumed by workers during working hours is considered for the effect on the environment of a structure.

$$\mathrm{LCEF}_m = \frac{d_w}{365} . f_d \left\{\sum\left(\frac{C_{fi}}{Y_{fi}}\right) . e_i + \sum(C_{\text{fuel}_j} . \lambda_j) . \frac{(1-S_{oc})}{A_f} . e_{CO_2\text{land}}\right\} \tag{5}$$

Life Cycle Ecological Footprint of Waste Disposal ($LCEF_{we}$):

The structure's waste for the most part results in transportation and landfill disposal of the materials while transportation is considered in the transportation area.

$$LCEF_{we} = \sum \frac{W_{dw_i}}{Y_{dw_i}} . e_{landfill} \tag{6}$$

Life Cycle Ecological Footprint of Water Consumption ($LCEF_w$):

The water consumption during the life cycle of a building largely remains undocumented in India. Water consumption mainly results in construction and operation phase while demolition phase does not consider it because of very less amount of water need.

$$\mathrm{LCEF_w} = C_w . E_w \lambda_i . \frac{(1 - S_{oc})}{A_f} \} e_{CO_2 land} \tag{7}$$

Life Cycle Ecological Footprint of Built-up Land ($LCEF_{built-up}$):

The direct physical land use for construction is discuss in this section.

$$\mathrm{LCEF_{built-up}} = A_b . e_{built-upland} \tag{8}$$

Average Annual Ecological Footprint of a household

For the estimation of the average annual ecological footprint (EF_{avg}) of a household building, the total lifespan of the building had been taken as 100 years. The average annual ecological footprint (EF_{avg}) of the building is calculated by given formula:

$$EF_{avg} = \frac{\text{Life cycle ecological footprint of a building } (LCEF_{total})}{\text{Building life span}} \tag{9}$$

The average annual ecological footprint per resident ($EF_{avg/resident}$) of a household building for a year session is given as follows:

$$EF_{avg/resident} = \frac{\text{Life cycle Ecological Footprint of a building}}{\text{Building life span} \times \text{No. of residents in a year}} \tag{10}$$

VI. RESULTS AND DATA ANALYSIS

Results of Life cycle Ecological Footprint of residential area in study area:

Table 6: LCEF $_{total}$ – Parameters

Parameter	EF (gha)		Percentage	
$LCEF_{e\&m}$	68,93,826	gha	93	%
$LCEF_w$	27,151	gha	0.3661	%
$LCEF_t$	4,77,847	gha	6.44	%
$LCEF_{we}$	2,137	gha	0.0288	%
$LCEF_m$	15,527	gha	0.21	%
$LCEF_{built-up}$	0.035	gha	0.0000005	%
$LCEF_{total}$	74,16,488	gha	100	%
EF_{avg}	74,165	gha/year		
$EF_{avg/resident}$	12,361	gha/m$_2$-year		

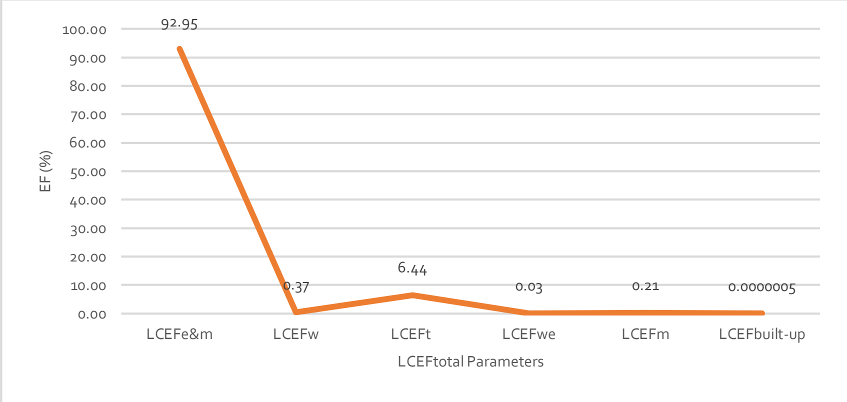

Figure 13: EF (%) of all parameters of $LCEF_{total}$

Life Cycle Ecological Footprint of Energy and Materials Consumption ($LCEF_{e\&m}$):

The contribution of Ecological Footprint of the building's operational energy is approximately two-third of the total $LCEF_{e\&m}$.
$LCEF_{e\&m}$ = **68,93,826 gha** (93 %)

Life Cycle Ecological Footprint of Water Consumption ($LCEF_w$):

The water is mostly consumed during the construction and operation phase of the building; the result of consumption is 29,789.03 m3 of water.
$LCEF_w$ = **27,151 gha** (0.3661 %)

Life Cycle Ecological Footprint of Transportation ($LCEF_t$):

The location of a construction site is a major factor for the transportation of materials, workers and C&D waste during the life cycle of a building.
$LCEF_t$ = **4,77,847 gha** (6.44 %)

Life Cycle Ecological Footprint of Waste Disposal ($LCEF_{we}$):

The generation of waste during building life i.e., construction and demolition, as well as, the amount of waste generated by the household during the operational phase throughout the life cycle.
$LCEF_{we}$ = **2,137 gha** (0.0288 %)

Life Cycle Ecological Footprint of Manpower ($LCEF_m$):

The total number of labour-days is about 4720 during the life of the building. Food consumption (energy needed to do the work involved also known as 'fuel') by the labours during the working hours is considered for the impact on the environment of the building.
$LCEF_m$ = **15,527 gha** (0.21 %)

Life Cycle Ecological Footprint of Built-up Land ($LCEF_{built\text{-}up}$):

The total land used for built up must be considered that are used for household construction. $LCEF_{built\text{-}up}$ = **0.035 gha** (0.0000005 %)

Average Annual Ecological Footprint of an Household building (EF_{avg})

The EF_{avg} of the household required several times more than the actual land of the plot area.
Ef_{avg} = **74,165 gha/year**

The average annual ecological footprint per resident ($EF_{avg/resident}$)

The $EF_{avg/resident}$ of the household required about several times more bio-productive land than the built-up area of the household. $EF_{avg/resident}$ = **12,361 gha/m^2-year**

VII. Inference and Conclusion

Inference

Ecological footprint is dependent on the culture, the technology available to the resident of that particular area, and the laws and limits related to environmental regulation the public authority sets up. The cut-off points to our natural resources are communicated from various perspectives, for example, biodiversity loss, topsoil depletion, the breakdown of fish stocks, and so on. Understanding how to reduce ecological footprints is a key step in repairing our relationship with the biosphere and developing more sustainable approaches to living and development. The study revealed that carrying capacity of the region qualitative and quantitative is not being effectively addressed, since there is lack of concern regarding the built environment during the development of a region and considerable increase in the ecological footprint. It also revealed that shelter footprint, which mainly depends on the house area usage and number of occupants, is very high in the urban areas.

This case study assesses the ecological impact of a household unit in Tirurangadi during its life span. The results obtained from such a study may be helpful in proposing and evaluating strategies for reduction in Ecological Footprint of household buildings in Tirurangadi municipality. Ecological footprint is dependent on the culture, the technology available to the resident of that particular area, and the laws and limits related to environmental regulation the government puts in place. It is intended to support building sustainability by conveying a practical method to assess life cycle ecological footprint as a sustainability indicator. By investigating the $LCEF_{total}$ of a structure, the structure compared and differentiated dependent on their Ecological Footprint.

With this assessment, the effects of energy and material consumption during the building life is highly significant and have the largest share in the $LCEF_{total}$ (i.e. around 90%) of the building. For this kind of action, transportation, water, manpower, and waste absorption convey low effects as demonstrated through this study. Therefore, this study is conducted so common man can understand or can draw conclusions regarding the need of accessing resources for construction of household and make the knowledge about environment sustainability during every built-environments life cycle easy to understand. The results obtained from such a study may be helpful in proposing and evaluating strategies for reduction in Ecological Footprint of household buildings.

Conclusions

Current examination on a building's ecological footprint is kept to incorporating the ecological footprint during the development time frame into the investigation model for computation. This examination can add to the absence of exploration with respect to the complete ecological footprint in whole life-cycle of a structure for the design stage, construction stage, operation stage, and demolition stage in related research.

VIII. GUIDELINES, POLICIES, STRATEGIES AND IMPLEMENTATION OPTIONS FOR OPTIMUM CARRYING CAPACITY

To reduce the whole life-cycle ecological footprint of houses in Tirurangadi region, Malappuram there are multiple approaches is needed to sustain immediate social needs and economic activities as well as long term needs of the environment. Present urban shelter forms are not efficient in terms of energy and material consumption. Considerations also need be made towards sustaining the long-term needs of the environment. Micro and macro shelter aspects lack any form of public participation and inputs, and developed on the basis of perceptions and presumptions of builders and policy makers. Despite a variety of alternative options being available in the market most materials used in present urban shelter units conventional materials like brick, which at present are inefficiently produced.

Application of proposed recommendations to existing case study.

After applying few of the above recommendations to the existing parameters of $LCEF_{total}$ for Household (Cluster Type B), there were significant changes in the footprint values.

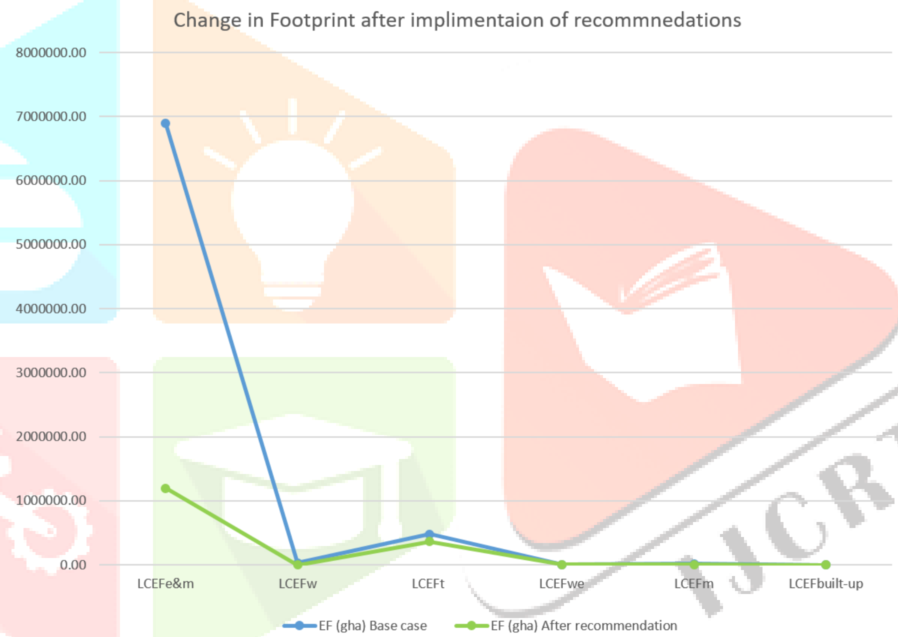

Figure 14: Change in Footprint after implementation of recommendations

The overall reduction in $LCEF_{total}$ for Household (Cluster Type B) after implementation of suggested recommendations is 78.88%

Table 7: *Implementation of suggested recommendations*

Energy and Materials Footprint	After replacement of materials used (recycled steel, clay tiles, biodiesel) it was found there was 82.62% reduction in the $LCEF_{e\&m}$ footprint value.
Water consumption Footprint	After replacing fuels to biofuels to extract water from ground water sources there is 99.99% reduction in the $LCEF_w$ footprint value.
Transportation Footprint	Depending on resources that are locally produced and closer location of the resource from the construction site showed a significant reduction in $LCEF_t$ footprint (about 23.82%).
Waste Disposal Footprint	Resorting to deconstruction, retrofitting and refurbishment than demolition. Before construction detailed inventory to have the right amount of each material. As well as a zero waste lifestyle will contribute to significant reduction of waste generated.
Manpower Footprint	The type of fuel consumed during the building life cycle, can help in reduction of manpower footprint values to around 86.58%.
Built-up land Footprint	Reducing the ground cover/ plot area ratio to 40 -50 percent will have 30.30% reduction.

It can be shown that as well as the general sense of well-being associated with contributing towards the preservation of the planet and the larger community, a strong case can be made for the business benefits of adopting a "green" approach. There is an always expanding rundown of exhibit undertakings and contextual analyses which show how this has been accomplished, while the House Builders' Federation as of late dispatched another housing sustainability award in organization with the World Wildlife Fund, subtleties of which are accessible on their site at www.hbf.co.uk. Assuming, nonetheless, the idea isn't to be dismissed and should be implemented appropriately.

REFERENCES

[1] "Resources & Consumption," 2020. [Online]. Available: https://populationmatters.org/the-facts/resources-consumption.

[2] Y. Zhao and X. Liu, "Estimation of sustainable development of residential projects based on ecological footprint.," *Journal of Northwest University,* pp. Vol. 8, 703–707, 2010.

[3] Y. Zhe and Y. Ying, "Green Building Assessment Based on Ecological Footprint," *Build. Econ,* pp. Vol. 3, 96–100., 2011.

[4] R. D. M. L. B. M. D. S. C. B. &. G. M. Eamer J, "The Living Planet Index in: Living Planet Report 2012," Zoological Society of London, WWF, Gland, Switzerland., 2012.

[5] R. G. M. a. P. T. (. Almond, "LIVING PLANET REPORT 2020 - BENDING THE CURVE OF BIODIVERSITY LOSS," WWF, WWF, Gland, Switzerland., 2020.

[6] "11.09 million vacant houses in India - High potential for Institutional rental housing: Report," 14 October 2019. [Online]. Available: https://www.moneycontrol.com/news/business/real-estate/11-09-million-vacant-houses-in-india-high-potential-for-institutional-rental-housing-report-4531181.html.

[7] J. Liu, G. Daily, P. Ehrlich and G. Luck, "Effects of household dynamics on resource consumption and biodiversity," *Nature,* p. Vol. 421, 2003.

[8] K.N.Ganesh and Project team, "Socio-cultural Processes and Livelihood Patterns at Tirurangadi - A Micro Historical Study," CENTRE FOR DEVELOPMENT STUDIES, Thiruvananthapuram, Kerala, India, 2011, 15 March.

[9] Dilawar Husain, Ravi Prakash, "Ecological Footprint Assessment and Reduction of an Academic Building in Shahdol (India)," *European Journal of Sustainable Development,* pp. Volume 2 Issue 4, Article No: 42, October 4, 2018.

[10] "Global Footprint Network. Ecological Wealth of Nations," 2017. [Online]. Available: http://www.footprintnetwork.org/content/documents/ecological_footprint_nations/ecological.html .

[11] "Brief Industrial Profile of Malappuram District," Ministry of Macro, Small & Medium Enterprise – Development Institute, Thrissur, 2017-18.

[12] Jaime Solís-Guzmán, Madelyn Marrero, Antonio Ramírez-de-Arellano, "Methodology for determining the ecological footprint of the construction of residential buildings in Andalusia (Spain)," *Ecological Indicators Volume 25,* pp. Pages 239-249, February 2013.

[13] Athira Ravi, Subha V., "Ecological Footprint Analysis – An Overview," *American Journal of Engineering Research (AJER),* pp. Volume-1 Pages 12-19, 2013.

[14] S. Bastianoni, A. Galli, V. Niccolucci & R. M. Pulselli, "The Sustainable City IV: Urban Regeneration and Sustainability-The ecological footprint of building construction," *WIT Transactions on Ecology and the Environment,* pp. Pages 345-356, 2006.

[15] "Bridging the Urban Housing Shortage in India," NAREDCO and KPMG, 2012.

[16] "Amendments in Model Building Bye-Laws (MBBL - 2016) for Electric Vehicle Charging Infrastructure," February 2019. [Online]. Available: http://mohua.gov.in/upload/whatsnew/5c6e472b20d0aGuidelines%20(EVCI).pdf.

[17] "Status of Urban Solid Waste Management in Kerala," 30 June 2017. [Online]. Available: sanitation.kerala.gov.in › uploads › SWM_data_in_ULBs.

[18] "Reducing Your Transportation Footprint," 2020. [Online]. Available: https://www.c2es.org/content/reducing-your-transportation-footprint/.

[19] D. Husain and R. Prakash, "Ecological Footprint Assessment and Reduction of an Academic Building in Shahdol (India)," *European Journal of Sustainable Development*, pp. Vol. 2 Issue 4, Article No: 42, 2018.

[20] B. Z. J. R. C. L. J. Y. a. Q. H. Ming Liu, "Whole Life-Cycle Ecological Footprint of Rural Existing Houses in Northern China," *Buildings*, pp. Vol. 8, 92, 2018.