National Energy Symposium

2014

21st November 2014

BMICH, Colombo 07, Sri Lanka

Organized by

Sri Lanka Sustainable Energy Authority

Ministry of Environment & Renewable Energy

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Message from the Minister of Environment & Renewable Energy

Sri Lanka has a good potential of renewable energy resources, and we have to develop resources as well as adopt technologies to suit to our country, in order to meet the future energy needs through such sources. The national policy document, "Mahinda Chinthana" has set sustainable energy targets as 20% of non conventional renewable energy to the grid electricity generation by 2020 and achieving reduction of 20% of energy consumption of year 2010, by 2020.

We have already achieved successful milestones in the national targets, and research & development interventions will of immense support in the national journey of sustainable development. I believe that National Energy Symposium will provide opportunity to liaise all energy stakeholders, including energy professionals, academia and general public towards a wide dialogue on sustainable energy, providing fruitful suggestions for future programmes in sustainable energy development.

I wish success of the programme.

Hon. Susil Premajayantha
Minister of Environment & Renewable Energy

Message from the Secretary of Environment & Renewable Energy

Sustainable energy is identified as one of the potential options for cushioning both energy and environment related issues. In order to have high impacts of sustainable energy, the concepts have to be interwoven to the society and research & development is a major part of it.

Networking among national and international universities, research institutions, etc. and developing mechanisms to identify solutions to technological issues of sustainable energy are primary requirements of sustainable energy research. That in turn warrants sustainable interventions to play a major role in the economic development of the country.

The National Energy Symposium organized by Sri Lanka Sustainable Energy Authority will be a good opportunity for different sectors and stakeholders to present findings of sustainable energy research at a national forum, which will eventually provide inputs towards the national programmes being implemented.

B.M.U.D. Basnayake
Secretary
Ministry of Environment & Renewable Energy

Message from the Chairman of Sri Lanka Sustainable Energy Authority

Sri Lanka Sustainable Energy Authority is the focal national entity for establishing energy sustainability of the country, and many interventions are being made in that line, including the promotion of sustainable energy.

The annual sustainable energy event – National Energy Symposium is one of the engagements under that mainly focusing research and development activities in sustainable energy. It is a forum for publishing R & D outcomes and other important work related to the subject. It is expected to be a very useful event for academia, researchers, knowledge seekers, professionals, scientists and people who are enthusiastic on sustainable energy.

I wish that National Energy Symposium 2014 will accomplish productive outputs in context of national sustainable energy development programme.

Prasad Galhena
Chairman
Sri Lanka Sustainable Energy Authority

Designing and Analysis of Solar and Grid Connected Hybrid Electricity System for Domestic Use

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Abstract

Domestic sector lighting and refrigeration are the two main areas contributing significant factors to overall electricity consumption in the world. As a country Sri Lanka has several electricity generation sources such as hydro, coal, diesel, etc. But nowadays more than 65% of electricity is produced with diesel and coal. Hence, the electricity charges of Sri Lanka are rising dramatically and this will become a huge burden for domestic electricity consumers. Therefore, this study is carried out to design a solar and grid powered hybrid electricity supply for domestic users and analysis of costs and benefits of the system. A newly designed solar system was integrated to the house while grid connection was also available. This integration was automated with aprogrammable switch system. For cost benefit analysis of the system, the grid electricity usage was recorded without the solar system for one month. The grid electricity usage with thesystem installed including automatic shifting was recorded. The collected data were compared using paired T-test. In addition to that environmental benefit of the system was analyzed. The grid electricity usage was reduced by 29 kWh inthe integration system. The reduction percentage of the electricity bill is 37.2%. The results reveal that there is a significant reduction of electricity bill after the system was introduced with automatic shifting. Therefore, the system can be considered as economically profitable with a capital payback time of 6 years. For environmental benefit analysis greenhouse gas emissions were considered as the unit of analysis. The carbon foot print of the electricity generated by solar panel and grid electricity were compared. According to theanalysis, thesystem could prevent the emission of 1.29 Mt CO2-eq to the atmosphere for a 10-year period. Therefore,the system can be introduced as an economically benefited and environmental friendly electricity system.

Keywords: Electricity usage, Integration, Solar electricity, carbon foot print

Introduction

Household electricity use generally makes up about a third of total electricity consumption in most of the countries. Sri Lanka meets its power requirement mainly through hydro, coal, and diesel. In present scenario more than 65% of electricity is produced with thermal energy [1].With increasing theprice of fossil fuel, the electricity charges are also increased dramatically and this will become ahuge burden for the most of the domestic electricityconsumers.

A Hybrid Electricity System (HES) is a combination of two or more energy sources with fossil fuel powered generator to provide the electric power[2]. HES has been received much attention over the past decades with increasing fossil fuel prices.

The sun is the basic energy source of the earth. Solar energy is essential for the achievement of an ecological sustainability with the photosynthesis. On other hand, solar energy is an alternative source of energy for power generation. Solar electricity is the technology of converting sunlight directlyintoelectricity. It is based on photovoltaic or solar modules which are very reliable and do not require any fuel or continuous servicing. Millions of solar modules are in constant use throughout the world, supplying electricity for communication, transport aids, healthcare, security systems, and many other applications.

Sri Lanka is an island in the South East of the Indian sub-continent. As Sri Lanka is situated near the equator, it receives an abundant supply of solar radiation throughout the year. There are no seasonal variations in the solar radiation but a spatial differentiation can be seen in the low lands and mountain areas.

As it is measured, the dry zone of the country receives a solar radiation varying from 4.5 – 6.0 kWh/m^2/day. But in the hill country, the solar radiation is as low as 2.0 – 3.5 kWh/m^2/day since the sky is so cloudy [3]. As a whole, in the dry zones of Sri Lanka there is a potential of harnessing solar energy. But use of solar power for the production of electrical energy is not much popular among the people of the country.

Household electricity consumption in the country significantly increased in the last two decades for two major reasons, expansion of rural electricity distribution programs and dramatic increase of types of energy consuming equipment in use. Also Sri Lanka raised electricity tariffs several times within the past few yearsas shown in Figure 01 [4].

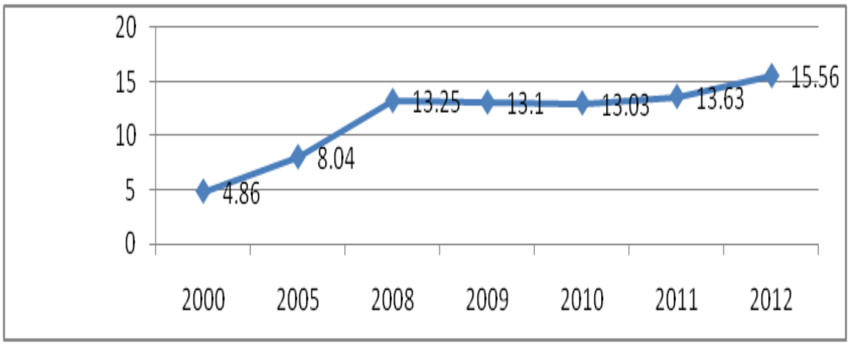

Figure 01: Variation of Average Selling price of kWh in Sri Lanka
Source-Sri Lanka Energy Balance 2012

As Sri Lanka's hydropower generationis no longer able to meet the country's daily requirement, the CEB increasingly relies on costly imported fuel oil for generating electricity. Increased electricity bills account for a considerable portion of the living cost of Sri Lankans.Therefore going for renewable energy is a very judicious idea for the countries like Sri Lanka. Among the renewable energy sources available within the country, solar power has a huge demand.

It is true that producing electricity from solar cells reduces air pollutionand greenhouse gasemissions. But solar panels do not fall out of the sky – they have to be manufactured. Similar to computer chips, this is a dirty and energy-intensive process.Carbon Foot Print is a method which can beused to measure the environmental pollution of a product or aprocess. Carbon Foot Print is a measure of the total amount of carbon dioxide (CO_2) and methane (CH_4) emissions of a defined population, system or activity, considering all relevant sources, sinks and storage within the spatial and temporal boundary of the population, system or activity of interest[5].

All electricity generation technologies emit CO_2 at some point during their life.Life Cycle Assessment (LCA) enables us to take into account the entire life cycle stages, from cradle to grave, in measuring environmental and resource sustainability.

In Europe, electricity generation with coal emits 1000 gCO_2eq/kWh, 875 gCO_2eq/kWh from fossil fuel and 415 gCO_2eq/kWh from natural gases[5]. In Sri Lankanscenario grid electricity emits 630.2 g CO_2eq/kWh as an average[6,7].

As a solution for this problem, this study was carried out to design a solar and grid powered hybrid electricity supply for a domestic users and analyze the costs and benefits in real scenario. The specific objectives of the study are to designasolar and grid-connected hybrid electricity supply with least cost, to analyze costs and benefits and the environmental impact of the system.

Methodology

Designing of Solar and Grid connected hybrid system

A small off-grid solar system was designed according to the needs of the house which wasexpected to conduct the experiment and it was integrated to the house while the grid electricity connection is also available. The off-grid solar system consists of a96 W Solar panel, aSolar max Charge controller, anOptima Lead acid deep cycle Battery – 75 A and anSDA 1000 Inverter(DC-AC).

When integrating the system,4 separate bulbs which are used frequently (living room, kitchen,children's room and office room) were introduced with solar electricity, while the grid-connected bulbs also remained in the same positions. Separate switches were placed for those 4bulbs, close to the usual switches of grid-connected bulbs. Integrating of the system was done in two stages. In the first month shifting the connection between thesolar system and thegrid was done manually. In the second month the shifting was automated with a programmable switch system.

Residents were asked to switch on the bulbs operating with solar power as much as possible in the first month. In the second month the solar system was switched on automatically for a pre-programmed time period and the grid connection of the grid-tied bulbs were switched off simultaneously in that time period. When the solar system was switched off, grid connection isconnected back automatically. Even though this shifting occurred automatically thesolar electricity system and thegrid connection in the residence are two different systems which do not disturb the functioning of each other.

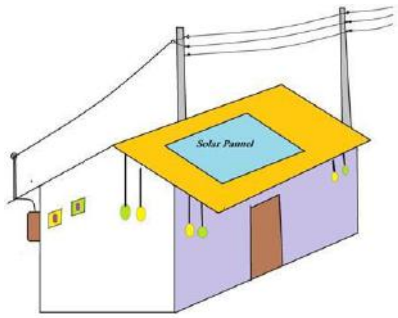

Figure 03: How two systems Functioning

In figure 03, yellow colour represents the bulbs and switches functioning with grid electricity and green colour represents the bulbs and switches functioning with solar electricity.

Analyzing costs and benefits of the system

It is aimed at finding whether the system is significantly beneficial or not. First the grid electricity usage was recorded without thesolar system for a given time period-one month. Then the grid electricity usage with the system installed (manual shifting) for a month was recorded. Thereafter the grid electricity usage with the system installed (automatic shifting) for a month was recorded. Thencollected data were compared with T-test.

1. Hypothesis

H_0–There is no significant reduction ingrid electricity consumption after the solar system is introduced with manual shifting

H_1- There is a significant reduction in grid electricity consumption after the solar system is introduced with manual shifting

2. Hypothesis-

H_0–There is no significant reduction in grid electricity consumption after the solar system is introduced with automatic shifting

H_1 - There is a significant reduction in grid electricity consumption after the solar system is introduced with automatic shifting

Future electricity price increases were forecasted with trend lines and the time required to generate profits with the system (to pay the capital) was found out.

Analyzing Environmental benefits of the system

For the environmental benefit analysis Carbon Foot prints were considered as theunit of analysis. The carbon foot print of the electricity generated by solar panel was calculated with the available secondary data. Also carbon foot print of the saved grid electricity was calculated. Then those data were compared.

The carbon foot print of the electricity generated by solar panel was calculated as a weight of GHGreleased per kWh of the electricity generated. For the ease of analysis all available data of CFP like lead acid battery and other electronic circuits were converted to the unit of -g CO_2eq per kWh.

Results and Discussion

Economic benefits of the Solar and Grid Connected HES

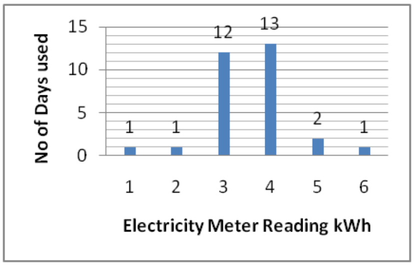

Figure 04: Grid Electricity usage, before HES introduced

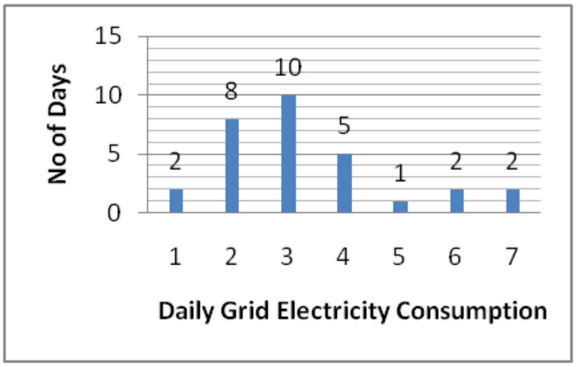

Figure 05: Daily Grid Electricity consumption after HES introduced with Manual Shifting

Figure 04 shows electricity usage of the house beforethe system introduced. According to these, data average daily electricity consumption was 4.5 kWh.Figure05 shows the electricity usage of house after the system was introduced with manual shifting. According to these data, average daily electricity consumption was 4.3 kWh.

1. Hypothesis

H_0–There is no significant reduction in grid electricity consumption after the solar system is introduced with manual shifting

H_1 -There is a significant reduction in grid electricity consumption after the solar system isintroduced with manual shifting

- November month data(before thesystem introduced) -
  4, 4,4, 5, 3, 6, 5, 5, 4,2, 5, 4, 5, 4, 7, 5, 5,4,5, 4, 5, 4, 5, 4, 5, 5, 4, 5, 4, 6
- December month data(after thesystem introduced with manual shifting)-
  5, 8, 6, 7, 5, 8, 5, 4, 4, 4, 3, 4, 4, 2, 4, 7, 3, 4, 4, 5, 3, 4, 3, 5, 3, 3, 4, 2, 3, 3

- Calculated p-Value = 0.487
  0.487>0.05

Therefore H_0 is not rejected.

There is no significant reduction in grid electricity consumption after the solar system was introduced with manual shifting. (μ_1=μ_2). Even though the 4 major bulbs were lit for a month with thesolar system the reduction in total electricity usage was only 8 kWh. Figure 06 shows how grid electricity consumption changed in two months.

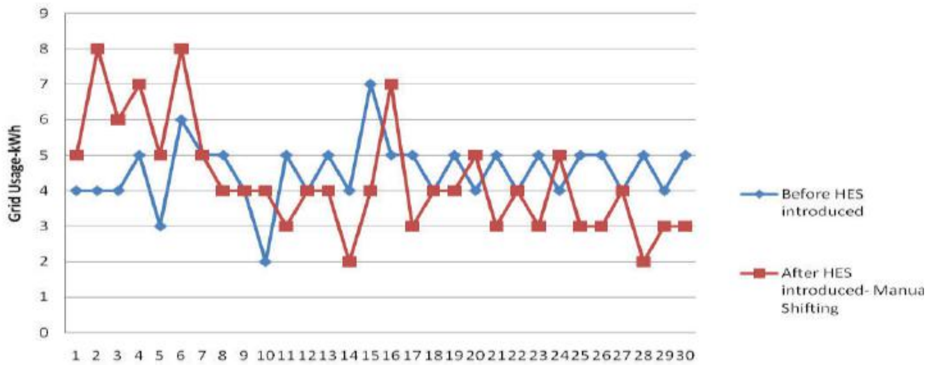

Figure 06: Daily grid electricity usage before HES introduced and after introduced with manual shifting

According to the on-line bill calculator of CEB the electricity bills for the two months are given below.

Table 01: November Month bill

Total kWh charge	Rs. 2273.50
Total fix Charge	Rs. 315.00
Total fuel Charge	Rs. 909.40
Total tax	Rs. 0.00
Total rebate	Rs. 0.00
Total charge	Rs. 3497.90

Table 02: December Month bill

Total kWh charge	Rs. 2029.50
Total fix Charge	Rs. 315.00
Total fuel Charge	Rs. 811.80
Total tax	Rs. 0.00
Total rebate	Rs. 0.00
Total charge	Rs. 3156.30

Electricity bill for November (before HES introduced) is Rs. 3497.90 (Table 01) and for December (after HES introduced) Rs. 3156.30(Table 02). The difference in the electricity bills was only Rs. 341/-. This is not a considerable reduction in the electricity bill. As a percentage the reduction is 9.7% only.

According to T test there is no significant change in grid electricity consumption after the solar system was introduced with manual shifting.There are two reasons which would be caused to this problem. First reason is the differences in the consumption patterns of the residencies. The second reason would be the human errors in the manual shifting method.

2. Hypothesis

H_0–There is no significant reduction in grid electricity consumption after the solar system is introduced with automatic shifting.

H_1 -There is a significant reduction in grid electricity consumption after the solar system is introduced with automatic shifting.

- Third month data (after HES introduced with automatic shifting) 3,3,4,3,4,3,4,4,4,3,4,4,3,3,4,4,4,3,4,4,3,5, 4,3,4,4,3,3,4,3
- Calculated p-Value =0.036

0.036<0.05

Therefore H_0 is rejected.

There is a significant reduction in grid electricity consumption after the solar system was introduced with automatic shifting. ($\mu_1 \neq \mu_2$)

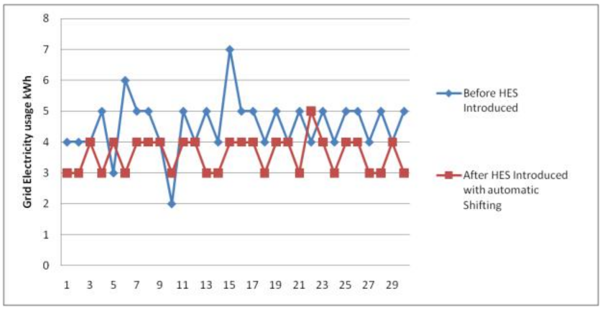

Figure 07: Daily grid electricity usage before HES introduced and after introduced with automatic shifting

When compared the total grid electricity consumption of third month (automatic shifted) with the November, there was a 29 kWh reduction in grid electricity usage. Figure 07 shows how grid electricity was consumed after and before thesystem introduced.

Table 03: November Month bill

Total kWH charge	Rs. 2273.50
Total fix Charge	Rs. 315.00
Total fuel Charge	Rs. 909.40
Total tax	Rs. 0.00
Total rebate	Rs. 0.00
Total charge	Rs. 3497.90

Table 04: Electricity bill for Third Month (automatic shifting)

Total kWh charge	Rs. 1342.00
Total fix charge	Rs. 315.00
Total fuel charge	Rs. 536.80
Total tax	Rs. 0.00
Total rebate	Rs. 0.00
Total charge	Rs. 2193.80

According to CEB on-line bill calculator electricity bill for November is Rs. 3497.90 (Table 03) and for third month it is Rs. 2193.80(Table 04). The difference in the electricity bills was Rs. 1304/-. As a percentage the reduction is 37.2%. Therefore this is a considerable reduction in the electricity bill for most of the domestic electricity consumers.

Cost component of the HES

The cost of the HES will be calculated according to current market prices of the components in the local market.

Table 05: Market Prices of components in HES

Item	Price(Rs.)
60 Wsolar panel	14000.00
10A, 12V charge controller	6000.00
12 V, 230 V inverter	11500.00
75 A lead acid battery	17000.00
Automatic timing switch	3000.00
Minor components	6000.00
Total charge	57500.00

Initial cost of this system will be around Rs. 57,500/-. After a five years' time the battery may have to be replaced. At that time,an additional cost of Rs. 18,000/- will be added to the cost.

Cost and benefit analysis was done based on 4 assumptions;

1. Life span of the system was assumed as 10 years.
2. Battery will be replaced once infive years.
3. The annual grid electricity price increment in Sri Lanka will be 4.21%.
4. Annual depreciation of the battery will be 5%.

Table 06: Commercial benefits of the system over 10 years

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Monthly Electricity bill without system	3497	3644.2237	3797.65	3957.526	4124.14	4297.76	4478.7	4667.254	4863.745	5068.509
Monthly Electricity bill with system introduced	2193	2285.3253	2381.54	2481.8	2586.28	2695.17	2808.63	2926.877	3050.098	3178.507
Savings of Money per month with HES	1304	1358.8984	1416.11	1475.726	1537.85	1602.6	1670.07	1740.377	1813.647	1890.002
Savings of Money per month with depreciation of battery	1304	1290.9535	1274.5	1254.367	1230.28	1338.37	1586.56	1566.339	1541.6	1512.001
Total Savings of money with HES per year	15648	15491.442	15294	15052.41	14763.4	16060.4	19038.8	18796.07	18499.2	18144.01
Cumulative Savings	15684	31175.442	46469.4	61521.82	76285.2	92345.6	111384	130180.4	148679.6	166823.7

The total cost of the solar and grid connected HES will be Rs.75,500/- with replacement cost of the battery in the5th year. As we can achieve this capital investment 5 yearsafter the system is installed, thecapital payback time of the system is 5 years. Thereafter the system will generate profits for rest of its life. According to calculations it will generate Rs. 91,323/= of profit on the 10-year time period (Table 06).

There are several other benefits of the system. The two components of this HES, grid power and solar power will be run as two separate systems. Any of the components has no impact on other component. For example, if there is a power cut, residents will be able to depend on the solar system. Same as if any problem occurred in solar system hey can depend on the grid electricity. Therefore no blackouttime will be faced by the owners with this system.

Even though thesystem is shifting automatically, there are two switches for manual shifting for any emergency situations like rainy days. With the depreciation of the lead acid battery the output of the solar system will be reduced with the time. Then blackouttimes may occur after two or three years. In such situations we can adjust the times in Programmable timing switch according to the capacity of the battery.

Environmental Benefits of the System

Calculating the Carbon Foot Print of the electricity produced by thesolar system

Assumption- Life span of all electric equipment is assumed as 10 years.

Calculating the CFP for Battery on kWh basis

Average CFP of Battery per kg	= 3910.77 g CO2-eq./kg [8]
Weight of Optima Battery used	= 19.7 kg
CFP of battery	=3910.77 g CO2-eq./kg * 19.7 kg
	=77042.169 g CO2-eq./Battery
Wh output of Optima Lead acid Battery	= 12 V * 75 Ah
	= 900Wh
Cycle Life of the Battery	= 1000 Charging cycles
Life time output of Battery	= 900* 1000
	= 900,000 Wh/Battery
CFP of Battery on kWh basis	$= \frac{77042.169 \text{ g CO2-eq./Battery}}{900 \; kWh \; / \; Batttery}$
	= 85.602 g CO2-eq./kWh

Calculating the CFP for Charge Controller on kWh basis

Average CFP of Integrated Circuitry	= $8{,}400{,}000 \; g \; CO2 \; eq \; / \; kg$ [9]
Weight of circuit parts in Charge Controller	= 30 g
CFP of Charge controller	$= \frac{8400000 \text{ g CO2 eq / kg}}{1000} * 30g$
	= 252000 g CO_2 eq. / Charge Controller
Wh output of Charge Controller	= 12 V * 20 Ah
	= 240 Wh
Expected Life Span of Charge Controller	= 10 years
Life time output of Charge Controller if Works 12 hours per day	= 240 Wh * 12* 365 * 10
	= 10,512,000 Wh/ Charge controller
CFP of Charge controller on kWh Basis	$= \frac{252000 \text{ g CO2 eq./ Charge Controller}}{10{,}512 \; kWh \; / \; ChargeController}$
	= 23.97 g CO2-eq./kWh

Calculating the CFP for Inverter on kWh basis

Weight of circuit parts in Inverter	= 100 g
CFP of Inverter	$= \frac{8400000 \text{ g CO2 eq / kg}}{1000} * 100g$
	= 840000 g CO_2 eq. / Inverter
Wh output of Inverter	= 900 Wh
Expected Life Span of Inverter	= 10 years

Life time output of Inverter if Works 7 hours per day	= 900 Wh * 7* 365 * 10 = 22995000 Wh/ Inverter
CFP of Inverter on kWh Basis	$= \frac{840000 \text{ g CO2 eq./ Inverter}}{22995 \text{ kWh / Inverter}}$ = 36.52 g CO2-eq./kWh

Calculating the CFP for Timing Switch on kWh basis

Weight of circuit parts in Timing Switch	= 140 g
CFP of Timing Switch	$= \frac{8400000 \text{ g CO2 eq / kg}}{1000} * 140g$ =1,176,000 g CO_2 eq. / Timing Switch
Wh output of Timing Switch	= 900 Wh
Expected Life Span of Timing Switch	= 10 years
Life time output of Timing Switch if Works 7 hours per day	= 900 Wh * 7* 365 * 10 = 22,995,000 Wh/ Timing switch
CFP of Timing Switch on kWh Basis	$= \frac{1{,}176{,}000 \text{g CO2 eq./ Timing Switch}}{22{,}995 \text{ kWh / Timing Switch}}$ = 51.14 g CO2-eq./kWh
CFP of multi-Si Solar panel	= 28g CO2-eq./kWh
CFP of Battery on kWh basis	= 85.60 g CO2-eq. /kWh
CFP of Charge controller on kWh Basis	=23.97 g CO2-eq./kWh
CFP of Inverter on kWh Basis	= 36.52 g CO2-eq./kWh
CFP of Timing Switch on kWh Basis	= 51.14 g CO2-eq./kWh
Total CFP of Solar Electricity	= 28+ 85.6+ 23.97+ 36.52+ 51.14 = 225. 25 g CO2-eq./kWh
Amount of Electricity used from solar system Per Month	= 25 kWh
Emissions of GHG from the used electricity of solar system per month	= 225. 25 g CO2-eq./kWh *25 kWh =5631.25g CO2-eq
Emissions of GHG from the used electricity of solar system per 10 year	= 5631.25 g CO2-eq *12* 10 =675 750g CO2-eq
CFP of Sri Lankan Grid Electricity	= 630.2 g CO_2eq/ kWh [10]
Emissions of GHG if that electricity is used from grid ,for 10 years	= 630.2 g CO2eq/ kWh* 26* 12*10 =1,966,224 gCO2-eq

According to the results obtained,it will prevent emission of 1,290,474 gCO_2-eq to the atmosphere for a 10-year periodby introducing the system.Therefore this hybrid electricity system can be introduced as an environmental friendly technology. With the introduction of the system the GHG emissions can be controlled significantly. If residents in the entire town apply this technology it will reduce a huge amount of GHG emissions to the atmosphere. Likewise if at least 50% of the households in a state apply suchhybrid systems the state will become an environmental friendly green state with very low GHG emissions values. Therefore developing this technology as a national concept would be very judicious for the well being of the mother earth in the future.

Conclusion

Solar and grid-powered hybrid energy system will be an economically profitable system.Domestic electricity bills could be significantly reduced with the system. According to analysis the capital payback time of the system will be 5 years. Also this system can be considered as an environmental friendly one.

Suggestions

- Promote solar electricity withinSri Lanka as HES rather than stand-alone solar systems.
- Make Aware the public about the advantages of solar electricity.
- Formulate a national policy on the solar energy utilization.
- Promote the solar electricity on a national theme like “Go Green with Solar Power”
- Reduce the taxes in solar panel importing.
- Start manufacturing of solar panels within thecountry.
- Give subsidy to install the systems for residencies and encourage the public to utilize solar energy.

Future Research Potentials

- Study the applicability of the system for different income levels.
- Combine the other renewable energy sources like bio gas, wind energy to the system.
- Introduce the application of renewable energy for other household devices like television, computer etc.

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Development of Configurators to Assist in the Selection of Domestic Solar Home Systems

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Abstract

Three configurators were developed to help the general public make informed decisions on the selection of suitable solar home systems. The objectives were to, calculate the impact on the monthly electricity bill with the addition and/or replacement of electric equipment in a home, optimise the selection of a suitable system based on string inverters and optimise the selection of a suitable system based on micro-inverters. All three configurators were developed on Microsoft Excel 2003 – 2007 compatible version. All rates were calculated based on the prevailing tariff. The addition/replacement of common electrical equipment were grouped under three categories as lighting, cooking and miscellaneous. If equipment is introduced, its monthly consumption was added, whereas, if equipment was to be replaced, its consumption was subtracted. Many of the companies provided information for string inverters, and therefore a separate configurator was made for string inverters and another was made for micro-inverters. Four matrices per company were generated as, number of panels per inverter, size of the system, cost of the system and sizes of panels in each system. With the publication of the Solar Resource Atlas of Sri Lanka in 2014, the configurators can be upgraded to give more precise estimates.

Introduction

Small Power Producer (SPP) program has been in operation in Sri Lanka since 1996, where a developer is allowed to finance and build a renewable-energy based power plant up to 10 MW, and sell its output to the grid at a standardised price. In addition to the above program, the Government made a policy decision in 2008 to allow any electricity customer who generates electricity using a renewable energy source to connect his facility to the distribution network. Unlike in the SPP program, these customer-owned facilities are expected to be of small capacity, and hence they would be allowed to be connected through the existing electricity connection of the customers' premises. Those are commonly termed distribution generation (DG systems). The customers' electricity purchase from the distribution network and the electricity exported by the customer to the distribution network are both measured. The customer shall be billed only for the net amount of energy purchased, and this system is generally referred to as net-metering. The net-metering policy originated in the USA, but has now spread in many countries. [1]

Net-metering Installations operated in Sri Lanka

Some common technologies used in net-metering include rooftop solar panels, energy storage devices, fuel cells, pico-hydro systems, small-scale wind turbines and combined heat and power systems. Customers with these types of generation systems connect to the local electricity grid and use the grid both to buy power when the DG systems are not producing sufficiently, and to sell power when excess is generated. Solar rooftop installations are by far the most common type among the different types of technologies eligible for net-metering [2].

CEB Distribution Licensees and Lanka Electricity Company (Pvt.) Limited have implemented the net-metering programme, with effect from June 1, 2010. [3] Both electricity distributors, that is, the Ceylon Electricity Board (CEB) and the Lanka Electricity Company Pvt. Ltd. (LECO), offer net-metering to their customers. Both regulations are nearly the same, with the only difference being the charges for net-metering installations. Net-metering involves a ten-year contract, a generation facility with a limit of 1 MW or the contract demand of the premises and any renewable resource for power generation. The surplus will be credited to the customer but no payment will be made for the surplus nor can the customer sell it to another customer [2].

Solar net-metering schemes gained much attention of the public in 2012, creating a dynamic industry. By end 2012, several net-metering installations with typical capacities of 2 – 5 kW have been in operation in the grid [4]. By end 2013, it was estimated that the total domestic net-metered installations of the country account for a total capacity of 3.3 MW, generating 4.2 GWh [5].

Scope of Work

There are many solar companies in Sri Lanka, which cater to the domestic sector. However, the prices of solar home systems, quality of panels/inverters, warranty…etc., vary widely among the companies. On the other hand, customers are unable to make intelligent decisions on the suitability of systems for their homes, owing to the myriad of information and disparity among prices in the market. Therefore, the SEA developed three configurators to help the general public make informed decisions on the selection of suitable solar home systems. The objectives were to;

Calculate the impact on the monthly electricity bill with the addition and/or replacement of electric equipment in a home

Optimise the selection of a suitable system based on string inverters

Optimise the selection of a suitable system based on micro-inverters

Methodology

Calculation of the likely monthly consumption with the addition and/or replacement of equipment

The additions/replacements of common electrical equipment were grouped under three categories as lighting, cooking and miscellaneous. The list of types of lamps considered, either for addition or replacement includes LED lamps, CFLs, fluorescent lamps, incandescent lamps and halogen lamps. The user was allowed to specify the wattage of the lamp, number of lamps and duration of use. For cooking appliances, rice cooker (750 W), toaster (750 W), electric kettle (1,000 W), electric mixer (150 W), blender/grinder (400 W), microwave oven (1,500 W) and electric coconut scraper (190 W) were used. The user was allowed to specify the number of items and duration of use.

For miscellaneous equipment, air-conditioner (1,000 W), CD player (20 W), ceiling fan (110 W), desktop computer (110 W), DVD player (20 W), immersion heater (1,200 W), geyser (2,500 W), television (100 W), normal iron (800 W), steam iron (2,200 W), pedestal fan (55 W), double door refrigerator (135 W), single door refrigerator (110 W), table fan (55 W), vacuum cleaner (125 W), washing machine (drying) (400 W), washing machine (front loading) (1,000 W), water pump (200 W) and the freezer (150 W). The user was allowed to specify the number of items and duration of use.

If an item of equipment is introduced to the present list of household items, its monthly electricity consumption was added to the present electricity consumption, whereas, if an item of equipment was to be replaced, its electricity consumption was subtracted from the present electricity consumption.

Optimise the selection of a suitable system based on string inverters

Information on capacities, prices, warranty, brand name, country of make of inverters and panels and types of panel were collected from companies through a questionnaire published on the website of Sri Lanka Sustainable

Energy Authority.. Additionally, the availability of insurance, after-sale services, inverter replacements and general contact details of companies too were collected.

Most of the companies provided information of string inverters, and therefore a separate configurator was made for string inverter. String inverter is the most commonly type in home and commercial solar power systems. It is a large box that is often situated some distance away from the solar array. Depending on the size of the installation, there may be more than one string inverter present. The advantages of using string inverters are that, it allows for high design flexibility, has high efficiency and robustness, availability for 3 phase variations, relatively low cost and has remote sensing capabilities. However, the high voltage levels accommodated by string inverters may present a potential safety hazard. They also do not have the facility for maximum power point tracking (MPPT) and individual panel level monitoring [6]. The methodology used for making the configurator is shown in Figure 1.

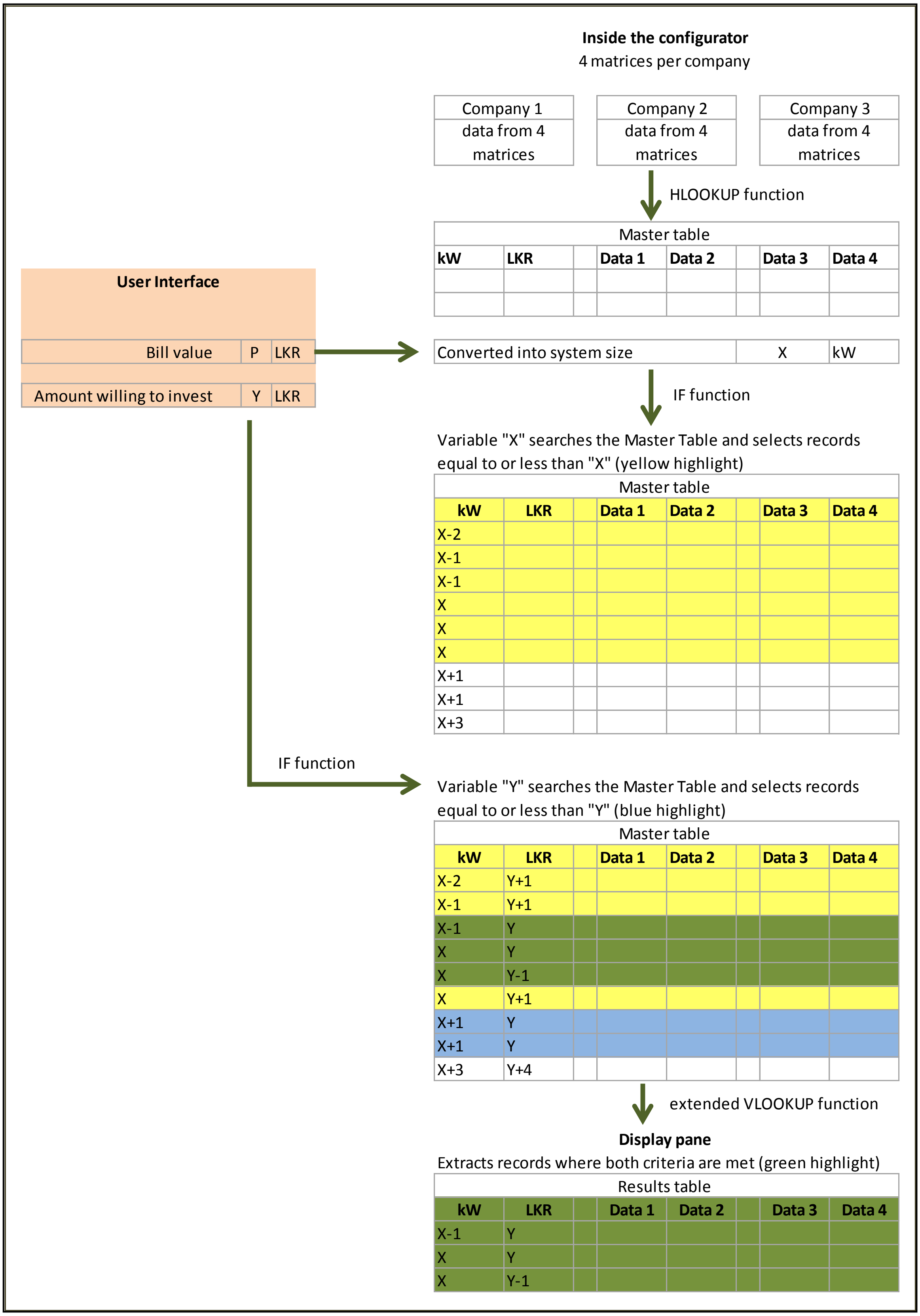

Figure 1: Methodology

Four matrices per company were generated as, number of panels per inverter, size of the system, cost of the system and sizes of panels in each system. Data from each of these matrices were extracted into a large table, using the HLOOKUP function in spread-sheets. The table had the column headings, system size (kW), system cost (LKR), panel size (Wp), name of the company, warranty period, country of make, warranty of inverter, country of inverter, brand name of inverter, brand name of panel, type of panel, number of panels, taxes, after sales services, inverter replacement, insurance and contact details. Users were allowed to enter the average monthly electricity bill (LKR/month) and the amount the user is willing to invest in a solar power system. The monthly electricity bill is converted into the number of units (kWh/month) and subsequently to the tentative size of the system (W). This value is used to search the large table using the "IF" function, and all systems that are equal to or less than the designated system sizes are displayed in a separate table, along with their prices. Out of these prices, the corresponding systems that are equal to or less than the amount the customer is willing to invest is selected and displayed, using the "IF" function again. Therefore, effectively, the configurator selects the list of systems which match the electricity bill of the customer and which are affordable to the particular customer. The results are extracted to a separate table using the extended VLOOKUP function and displayed to the customer. Details of the company for the selected system size, warranties, brand names, country of make…etc., are also displayed. The approximate bill after net-metering is calculated assuming that on average, 124 kWh are generated per 1 kW of installed capacity each month. The savings realised herein (LKR) are used to calculate the simple payback period, by dividing the costs by savings. The rooftop area needed for the installation is calculated taking that 10.7 sqft is 1sqm. These information too, is displayed for public consumption.

Optimise the selection of a suitable system based on micro-inverters

Among the information provided by companies, there were a few micro-inverters. Therefore, a separate configurator was made for micro-inverters. A micro-inverter consists of a small box located on the back of or situated very close to a solar panel, which converts the DC electricity produced by a single solar panel to AC. The advantages of micro-inverters are that, they have panel level MPPT also they increase system availability - a single malfunctioning panel will not have such an impact on the entire array, panel level monitoring, lower DC voltage, increasing safety, allowance for increased design flexibility where 8 modules can be oriented in different directions, increased yield from sites that suffer from overshadowing since one shadowed module doesn't affect a whole string. Also, there is possibility to use different makes/models of modules in one system, particularly when repairing or updating older systems [8] & [7]. The disadvantages include, higher costs, currently up to double the cost compared to string inverters, increased complexity in installation and increased maintenance costs due to there being multiple units in an array [8].

The methodology for making this configurator is similar to that of string inverters (Figure 1).

All three configurators were developed on Microsoft Excel 2003 – 2007 compatible version. Data entry by users was limited to cells highlighted in green, while results were displayed in cells highlighted in blue. Cells were selectively protected to avoid accidental modification of formulae. All rates were calculated based on the prevailing tariff [8].

Results and Discussion

Calculation of the likely monthly consumption with the addition and/or replacement of equipment

For a house that consumes 200 kWh at present, the new consumption would be 250 kWh, if the user replaces an incandescent lamp of 20 W, a florescent lamp with 60 W, a washing machine (drying) and add 3 CFLs of 30 W, one CFL of 20 W, one LED lamp with 20 W, one AC and one front loading washing machine. The new bill would be LKR 8,967 /month approx.

Instructions to users

Please fill in the green cells, by selecting values from the drop down menu

For items that you wish to add, fill the Tables on the left. For items that you wish to remove, fill the tables on the right.

Your likely new bill and generation will be displayed in the light blue cells.

Your monthly consumption	200	Units (kWh)
Additions/ Replacement total	**50**	Units (kWh)
Likely new bill	**8,967.00**	LKR

Items to be added

Table A — For frequent using of lighting equipment use Table

	Lighting	Nos.	Wattage (W)	Duration/ day (hrs)	kWh/month
1	Compact Fluorescent Lamps (CFL)	1	20	4	2.4
2	LED lamps	1	20	2	1.2
3	Compact Fluorescent Lamps (CFL)	3	30	2	5.4
4					

Table E — For frequent using of miscellaneous equipment use

	Miscellaneous equipment	Nos.	Wattage (W)	Duration/ day (hrs)	kWh/month
1	AC	1	1,000	1.25	37.5
2	Washing machine (front loading)	1	1,000	0.5	15

Items to be removed

Table A — For lighting equipment that was in use fre

Lighting	Nos.	Wattage (W)	Duration/ day (hrs)	kWh/month
Incandescent lamps	1	20	4	2.4
Compact Fluorescent Lamps (CFL)	1	60	2	3.6

Table E — For miscellaneous equipment that was in u

Miscellaneous equipment	Nos.	Wattage (W)	Duration/ day (hrs)	kWh/month
Washing machine (drying)	1	400	0.5	6

Figure 2: Snapshot of the public interface of the first configurator

Optimise the selection of a suitable system based on string inverters

For a house that consumes 250 kWh, and if the user is willing to invest LKR 350,000, solar home that are available in the market are displayed as shown in Figure 3.

This list of options are generated by sorting payback periods from the smallest value to the largest value | Back to Home Page

If you are willing to invest Rs. 350,000 the systems available in the market are given below.

Company name	System size available in market (W)	Listed price of system (Rs.)	Approximate monthly bill after net metering (Rs.)	Payback period (yrs)	Rooftop area required for installation		Panel size (W)	Brand of panel	Panel type	Panel - country of made
					sq ft	sq metres				
Illukkumbura & Sons (Pvt) Ltd	1,500	330,000	372	4.6	105	10	310	Cinco Nigbo	Mono-crystaline	China
Illukkumbura & Sons (Pvt) Ltd	1,500	331,000	372	4.6	105	10	250	Cinco Nigbo	Mono-crystaline	China
Illukkumbura & Sons (Pvt) Ltd	1,500	343,000	372	4.7	105	10	290	Cinco Nigbo	Mono-crystaline	China
Mackwoods Energy PLC	1,000	281,000	3,199	8.4	70	10	250	Canadian Solar	Poly-crystaline	China
Synex International (Pvt) Ltd	1,000	283,000	3,199	8.5	70	10	250	LIGHTWAY SOLAR MODULE	Mono-crystaline	China

Warranty for panel (yrs)	Provision of aftersales services	Insurance for panel	Brand of inverter	Inverter - country of made	Warranty for inverter (yrs)	Whether the inverter would be replaced during repair	Insurance for inverter	Contact person	Address	Contact details telephone/fax	Web/email
25 years, conditions apply	Yes	Can be provided. Conditions apply	GOODWE	China	5	Yes	Can be provided. Conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com
25 years, conditions apply	Yes	Can be provided. Conditions apply	GOODWE	China	5	Yes	Can be provided. Conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com
25 years, conditions apply	Yes	Can be provided. Conditions apply	GOODWE	China	5	Yes	Can be provided. Conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com
25	Yes	Applicable at additional cost	Samil power	China	5 years and extendable upto 20 years	Yes	Applicable at additional cost	Mr. W. D. Kularatne	10, Gnartha Pradeepa Mawatha, Colombo 08	Tp: 0711522784	www.mackwoodsenergy.com
10	Yes		Growatt	China	10	Yes (upto 5 yrs)		Mr. R. P. P. Senarathna - Managing Director	No. 24 A, Malwatta Avenue, Kohuwala, Nugegoda	Tp: 0114307816, 0114205139	www.synexint.com

Figure 3 : Solar home systems available in the market, with string inverters

Optimise the selection of a suitable system based on micro-inverters

For a house that consumes 250 kWh, and if the user is willing to invest LKR 350,000, solar home that are available in the market are displayed as shown in Figure 4.

This list of options are generated by sorting payback periods from the smallest value to the largest value — Back to Home Page

If you are willing to invest Rs. 350,000 the systems available in the market are given below.

Company name	System size available in market (W)	Listed price of system (Rs.)	Approximate monthly bill after net metering (Rs.)	Payback period (yrs)	Rooftop area required for installation		Size of panel (W)	Brand of panel	Panel type	Panel - country of made
					sq ft	sq metres				
Illukkumbura & Sons (Pvt) Ltd	1,240	275,000	2,030	5.7	87	10	310	Cinco Nigbo	Mono-crystaline	China
Illukkumbura & Sons (Pvt) Ltd	1,240	282,000	2,030	5.8	87	10	250	Cinco Nigbo	Mono-crystaline	China
Illukkumbura & Sons (Pvt) Ltd	1,240	292,000	2,030	6.0	87	10	290	Cinco Nigbo	Mono-crystaline	China
Illukkumbura & Sons (Pvt) Ltd	1,300	337,000	1,146	6.3	91	10	290	Cinco Nigbo	Mono-crystaline	China
Illukkumbura & Sons (Pvt) Ltd	1,300	337,000	1,146	6.3	91	10	290	Cinco Nigbo	Mono-crystaline	China

Warranty for panel (yrs)	Provision of aftersales services	Insurance for panel	Size of Micro Inverter (W)	Number of Micro inverters	Brand of inverter	Inverter - country of made	Warranty for inverter (yrs)	Whether the inverter would be	Insurance for inverter	Contact person	Address	Contact details telephone/fax	Web/email
25 yrs, conditions apply	Yes	Can be provided, conditions apply	620	2	APS	China	15	Yes	Can be provided, conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com
25 yrs, conditions apply	Yes	Can be provided, conditions apply	620	2	APS	China	15	Yes	Can be provided, conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com
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25 yrs, conditions apply	Yes	Can be provided, conditions apply	260	5	APS	China	15	Yes	Can be provided, conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com
25 yrs, conditions apply	Yes	Can be provided, conditions apply	260	5	INVOLA	China	10	Yes	Can be provided, conditions apply	Mr. Dananjaya Hettige	No. 486, Sri Sangaraja Mawatha, Colombo 12	Tp: 0112 332392, 0777 317646, fax: 0112 328481	www.aiksonlanka.com, solar@aiksonlanka.com, dananjayahettige@gmail.com

Figure 4: Solar home systems available in the market with micro-inverters

With the publication of the Solar Resource Atlas of Sri Lanka in 2014, [9] solar radiation levels and mounting angles for solar panels will be available at Divisional Secretariat level. This information can be used to upgrade the configurators to give more precise estimates.

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Advance Control System for Small Hydro Power Project

Kumara, P.G.A.

Abstract

Small hydro power projects play a significant role in renewable energy sector in Sri Lanka. Among different categories, community based and estate based hydro projects use electric load control technology since it can be locally manufactured, easily adopted in to old existing hydro plants and the low cost. However, power electronic control technology reduces the lifetime of the controller itself and the other components of the system; therefore it is not an efficient and viable technology in the present context. Most of the estate based hydro projects have been abandoned due to endless failures of the controller and damages to appliances. The maintenance cost for community based hydro power projects are very high and the fact that it surpasses the monthly income of the community. As a result this has led to unbearable expenditure on electricity as they have no other alternative solution. Ultimately, beneficiaries would expect electricity from the national grid while abandoning low cost and environment friendly energy resources and lose mutual understanding among the beneficiaries.

The controller determines the excess of generated power at a rate of hundred times per second and adjusts the ballast load capacity accordingly by electronically switching. Currently available controllers change the ballast load capacity by changing the triggering point from 0^0 to 180^0 in each half cycle of the wave and then calling the phase angle controller. This leads to noise generation, AC wave form distortion and very high Di/Dt when switching at the peak area of the AC wave. By introducing a multiple number of electric loads and switching logically selected loads at zero crossing point of AC waves, these bad effects can be avoided as it generates a pure sinusoidal wave. This paper reviews the theoretical analysis and field level experiences of several successful projects related to the technology of "Multiple loads, zero crossing point firing hydro power controller".

Key words: Stand-alone hydro power, Induction of generator controller (IGC), Electric load controller (ELC), Hydro power controller

Introduction

There are two types of technology used to control hydro power plants, namely flow controlling and electric load controlling. The flow control technology is used in relatively larger hydro power plants as expensive electromechanical components have to be used. However, the electric load controller is used in small hydro power plants because the capital cost is very low, applicable even to damaged flow control hydro power plants and there is no economical value for the excess power.

In the electric load controlling system, an electric heating load is used (also known as ballast load or dump load) equal or higher than the maximum generating capacity of a given project. This ballast heating load can be adjusted from 0% to 100% by electronically switching. By setting the sum of the village load and the ballast capacity equal to the generating capacity, the system voltage and frequency can bet maintained within the accepted limit.

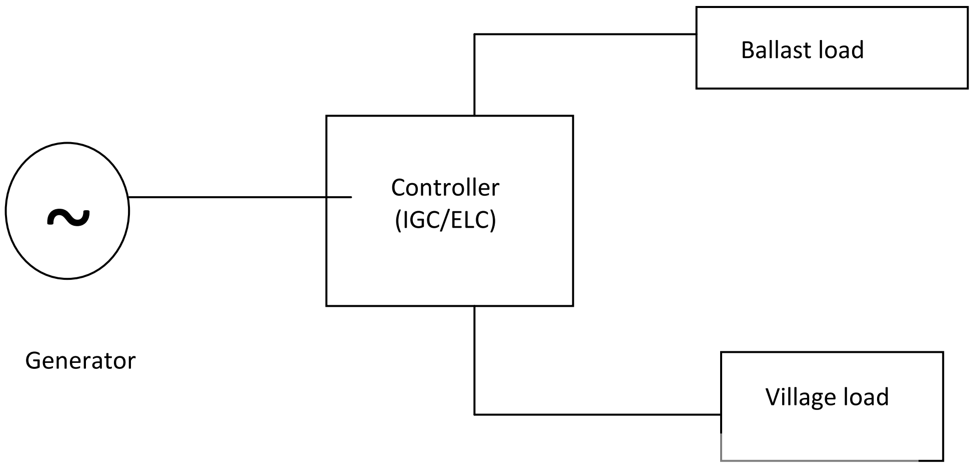
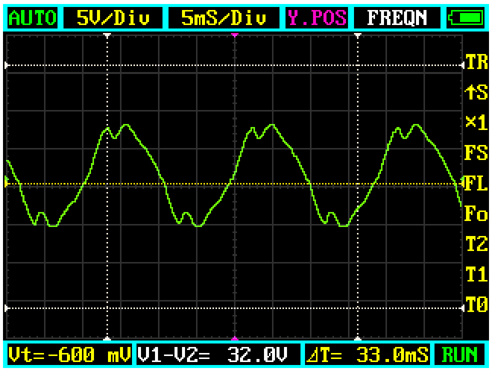
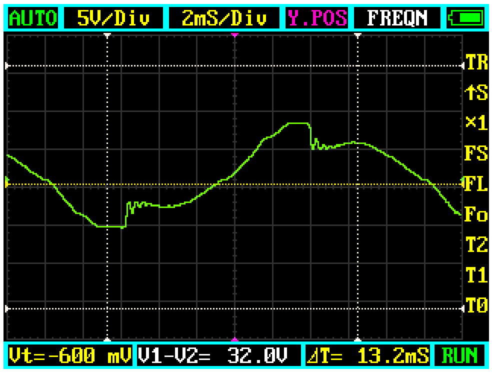


Figure 1: Ballast and user load connection

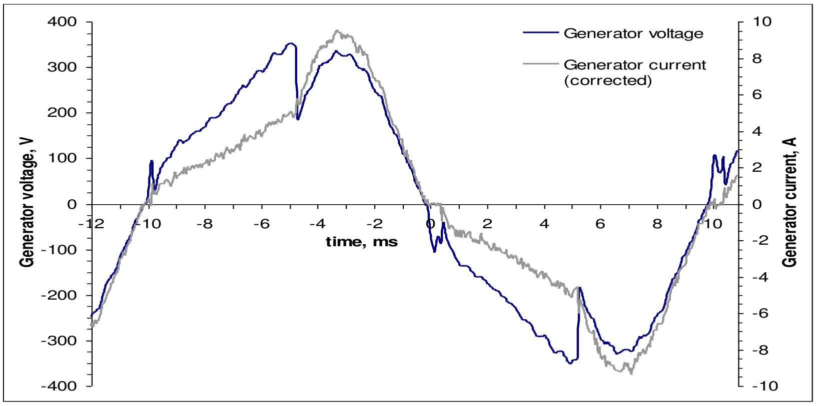
With currently available controllers, the ballast load switching point has to be adjusted throughout each cycle of the alternative current waves. When it reaches around 90 degree of each half cycle of the wave, the AC wave form gets distorted, which in turn badly affects all electromechanical equipment in households, power house and the controller itself. Professor Janake Ekanayake has stated that “In order to minimise further capital cost, crude voltage and frequency control techniques are used” [1]. According to the research conducted by REREDP, most of the controllers in VHP were not working and the ballast had been connected permanently. The active power demand is controlled by adjusting inlet valves time to time at different hours of the day [2]. Distorted wave form of few controllers is shown below.



a. **Udagama VHP Pallebadda**



b. Ilumbakanda VHP kalawana



c. **Humming bird ELC (source[3])**

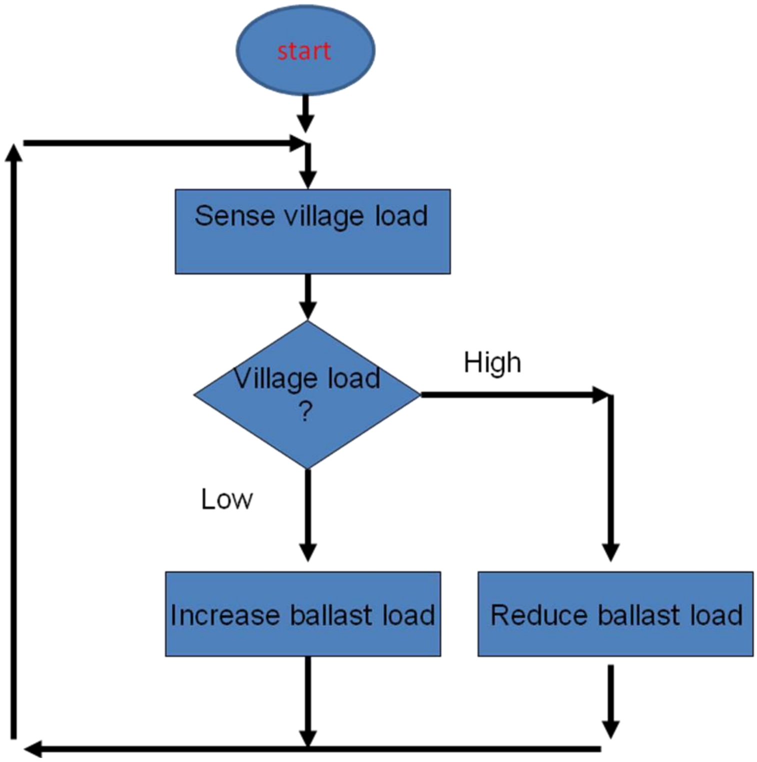
Figure 2: AC wave distortions in electric load controlling HP

These distortions in AC wave form lead to overheating of electrical and electronic components, development of cyclic loads on electromechanical components and consequent reduction of life time and efficiency [4].

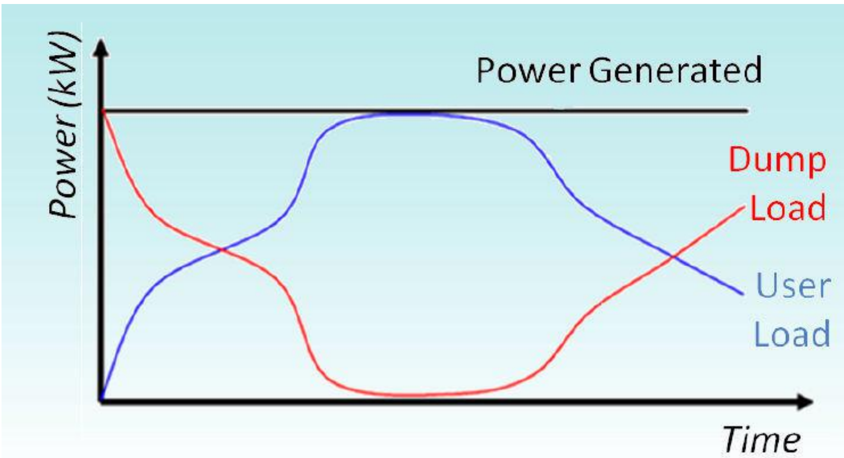
Technology and present controllers

Micro hydro controller is a feedback controlling system. It senses the system voltage and frequency in induction and synchronous generators respectively and electronically adjusts the ballast capacity so that the consumers demand and the ballast load together are equal to the generating power. At 50 Hz frequency, it adjusts the ballast output 100 times per second twice per cycle of AC wave form.

Figure 3 shows the endless feedback control loop and variations of generating power, user load and ballast load.



a) **Feedback control loop of electric load controller**



b) **Constant power generation and consumption while consumer load varies randomly (Source [5])**

Figure 3: Electric load controlling process

According to the literature survey, following three types of technology are identified to be available for changing the ballast capacity as [1] & [4];

- Binary weighted loads controller
- Phase angle controller
- Mark-space ratio controller

Althogh different technologies are used to sense the voltage and frequency, controllers are catagorised according to the ballast capacity changing/switching technology which is the most important factor in a controller. For the Binary weighted loads controller and Phase angle controller, a TRIAC is used as the electronic swtiching device which can direclty control AC power. For the Mark-space ratio controller, a different type of transistor is used as the switching device. All these transistors can only handle DC power. Therefore a rectifier bridge has to be used to convert AC power in to DC power. Next section gives a brief description of the power transistor and the TRIAC which are used as electronic switching devices in the above controllers.

Triac

TRIAC is a three-pinned AC switching device. By giving a very small triggering signal to the gate pin (Typically 15 mA, 20 μs) it acts as the ON switch until the next zero voltage point occurs. So it has to be given a gate signal in each half cycle to continuously maintain a constant ballast load. The parentage of heat dissipation from the ballast can be smoothly adjusted by changing the gate pulse location of each half cycle. Figure 4 shows 100% 50%, 25% and 0% percentages of power dissipation by changing gate triggering point. Gate pulse timing has been marked in arrows.

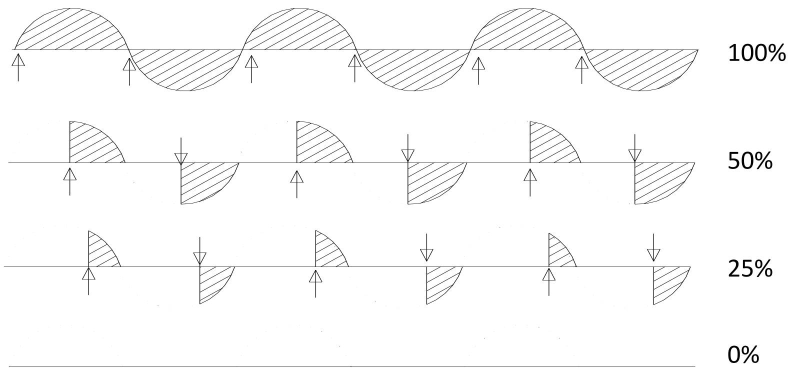


Figure 4: Wave form of a TRIAC controlled AC power system at different load percentages

Power transistor

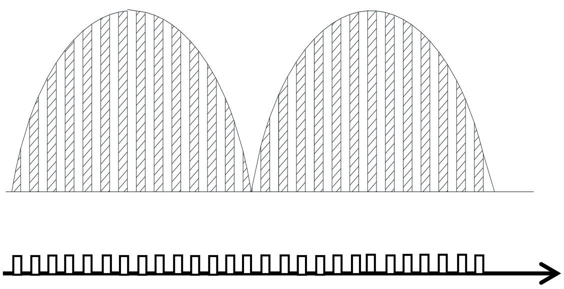


Figure 5: Transistor switching signal and *output wave form*

A transistor of IGBT or MOSFET family can be used as the DC power controlling device. These latch the ON state until gate pulse is there and as soon as gate pulse is OFF power line also turns off. The switching speed of these transistors extends up to kHz range. Hence it is clear that the ballast power can be controlled by adjusting the gate signal ON/OFF time. The figure 5 shows how the wave form of a non smooth rectified AC wave is controlled and the generated control signal.

Hatched area represents ON state of the transistor (mark) and the rest is OFF state (space). By increasing or decreasing the gate pulse times (mark), the dark column width can in turn be increased or decreased. That is how the ballast load in mark-space ratio controller is adjusted.

Binary weighted load controller

This is the first type of controller used in MH sector with simple electronics logics. Here a variable load is produced by switching in a combination of fixed resistors. The values of these resistors are binary weighted so as to maximize the number of load steps with a minimum number of loads and swithches. With an “n“ number of loads, 2^n number of combinations can be obtained. For example with three resistors seven combinations are possible as shown in the folowing figure.

a) Loads and switch connection **b) Load combinations**

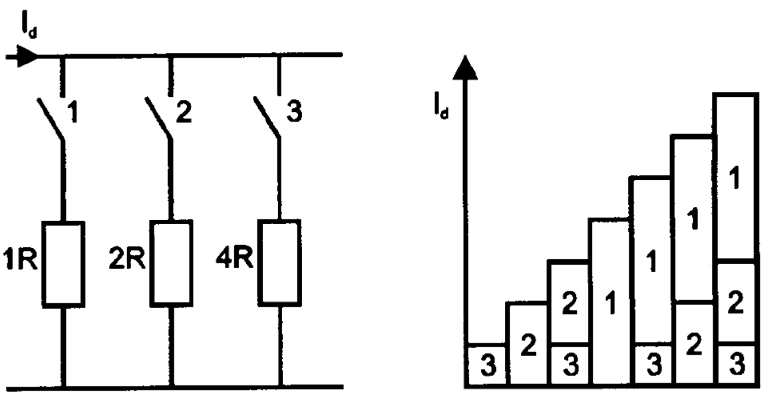


Fig. 6 - Binary Weighted load controller (source [4])

Here voltage distortion is minimum since pure resistive loads are used. Fig. 7 shows the wave form distortion at the switching of ballast at the peak area of AC wave. Furthermore, the voltage and frequency can change over a wide range due to a few number of loads and as a result it is not suitable for modern electrical appliances such as CFL/LED bulbs, TVs, motors, etc. On part load running (in dry season or off peak time), the voltage control is very poor as the smallest load step is very large with respect to the generating power.

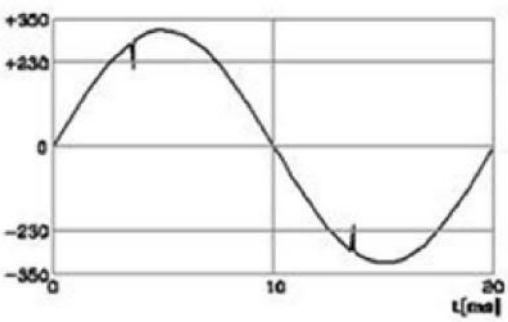
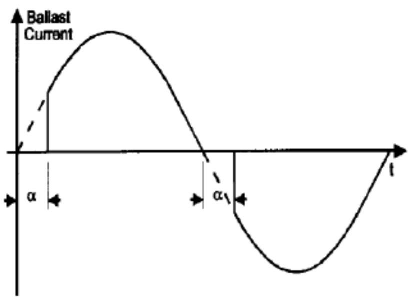


Figure 7: Wave form distortion when ballast turns ON in peak range of wave (source [5])

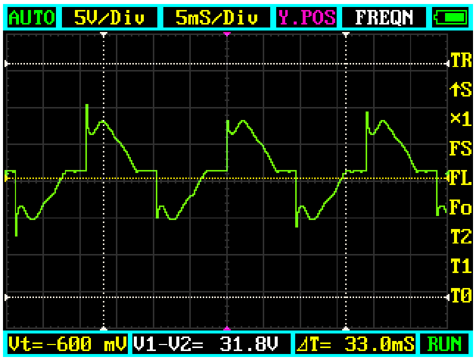


Phase angle controller

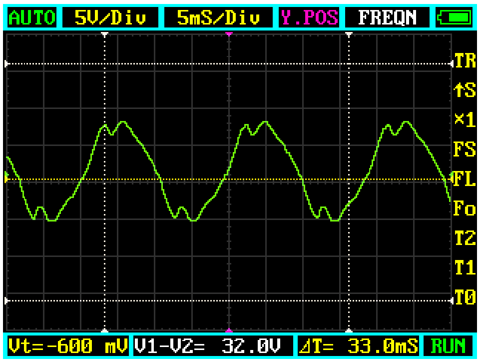
Figure 8: Phase angle control of TRIAC (source [4])

By changing triggering point of the TRIAC, a variable electrical load can be developed. The triggering angle α is changed from 0 to 180 degrees by an electronic circuit in Phase angle control type MH controller. In a binary weighted load controller, a single heating element can be used as the ballast. This means there is only a very simple electrical circuit there. But here the wave distorts drastically when the ballast turns on around 90 degree of each half wave. Fig.9 shows the ballast and user side wave forms. According to the ballast wave there is a very sharp voltage rise just after the TRIAC has turned on. Such a very high voltage gradient leads to increase of Di/Dt and reduction of the lifetime of TRIAC [3] & [8].

Controller 01

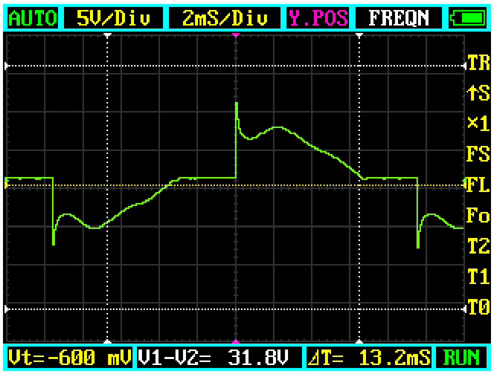


Ballast wave

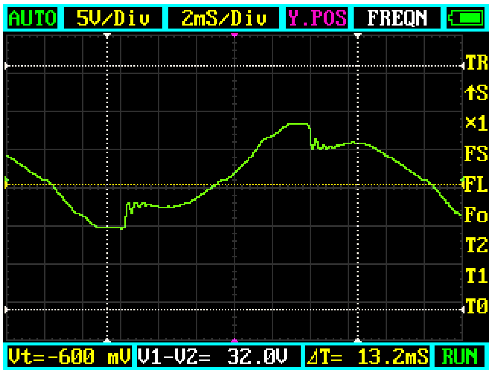


Consumer's wave

Controller 02

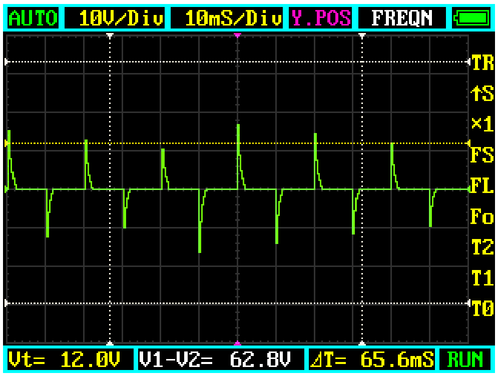


Ballast wave

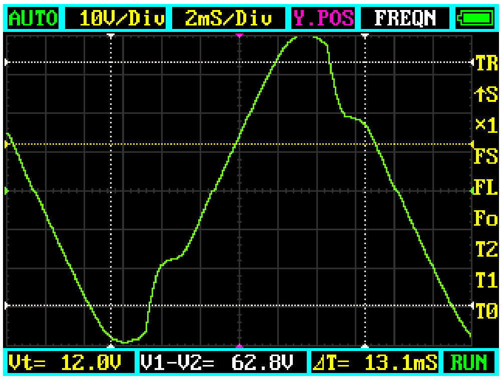


Consumer's wave

Controller 03



Ballast wave

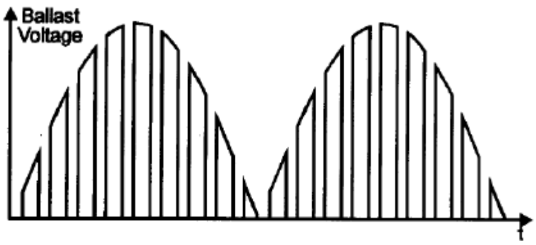


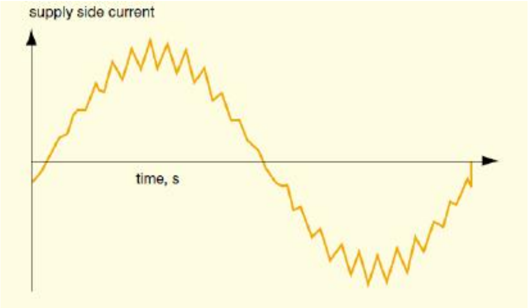
Consumer's wave

Fig.9: Ballast sand users wave form of a few phase angle controllers

Mark- Space controller

In this controller the ballast load connects across a Rectifier Bridge and a transistor. Then DC voltage is received by the transistor and it can be switched on and off at high speed. The control circuit determines ON (mark) and OFF (space) time, thus the process is called Mark-Space ratio. Modern electronic literature refers to this process as Pulse Width Modulation (PWM) [6]. The ballast and consumer wave forms of this control are shown in Fig. 10.





a) Ballast wave form **b) Consumer wave form**

Figure 10: Wave form of Mark- space controller (Source [1])

This is a very smooth controlling technology and the only bad effect is the generation of high frequencies which may affect radio frequency receivers such as radio, TV, wireless phone, etc.

History of electrical load controller

For first time in the early 1990s, the binary weighted controller has been used in Sri Lanka in community-based and estate hydro power projects by ITDG. Because of the relatively poor control of voltage and frequency, the binary weighted controller was in use only for a short period of time. Since a simple version of phase angle controller was introduced in late 1990s all suppliers have forgotten the binary weighted controller.

Since different versions of phase angle controllers have been introduced and even more are available freely on the Internet, this control technique is used by most of the suppliers. Voltage sensing, noise filtering and the protection level vary from model to model. This is the most popular type of controller up to date and technical data sheets of a few versions are available at the following links.

1. Humming bird controller, www.econologie.info/share/partager/Humbird-fra.doc
2. Electronic Load Control ELC ,From Remote HydroLight for Synchronous Generator
   by Anders Austegard , www.remotehydrolight.com/
3. *Renerconsys Digital load Controller (DLC) for* Induction Generator (IGC) *&*
   Synchronous generator (elc), www.renerconsys.com

4. Analog card by Remote HydroLight Anders Austegard Remote HydroLight (www.remotehydrolight.com)

Some versions of these controllers as well as other varieties of controllers are used in Sri Lanka too. Although these controllers do not suffer any short term failure, the life time of the excitation capacitor bank, bearing and generator decrease drastically. In most cases the capacitor catches fire which spreads up to the controller.

Mark-Space controller technology was introduced in Sri Lanka in year 2000 by ITDG. Although theoretically this is a very smooth controller, its life time is limited to a few months. Therefore no hydro power developer in Sri Lanka has used this technology for long.

Multiple loads, zero crossing point switching controller

Micro controller based digital electronics is widely used all over the world. “**Multiple loads, zero crossing point switching controller”** concept is based on microcontroller and binary weighted load controller technologies. It is discussed in the following section.

Methodology

Basically this controller consists of a microcontroller which measures the voltage and frequency of the current cycle of the wave and determines the next cycle ballast load, the protection system for surge, over and under voltage and frequency and adjustment system of voltage and frequency. Figure 11 shows the schematic diagram of this controller.

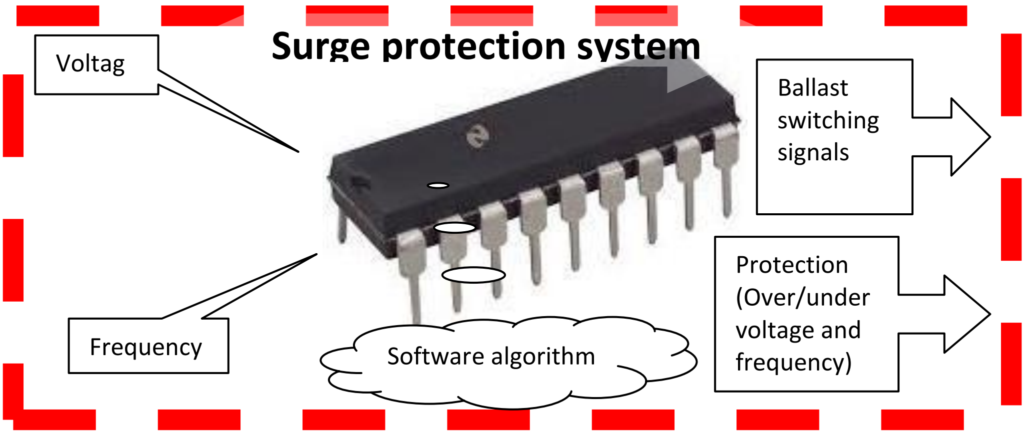


Figure 11: Schematic diagram of a Multiple Loads, zero crossing point switching controller

This control system operates with microcontrollers of 20 MHz processing speed and can measure the RMS value of voltage and frequency within less than 50 µsec.

Load variation sensing

Voltage and frequency are the sensing parameters of village load variation for the induction generators and synchronous generators respectively. Voltage samples are taken with 10 bits resolution (1024 readings) by the inbuilt analog to digital converter and it takes less than 15 µsec per reading. By taking over 100 readings it calculates average value. Based on inbuilt timers, the cycle duration of the AC wave is divided into 65,536 or 16 bit resolution and the frequency of wave form is calculated.

Controlling

Based on the above mentioned instantaneous reading, the set values and the error the control variable is generated. Using the proportional–integral–derivative (PID) algorithm, the next half cycle of AC waveform ballast load is identified in order to minimize the error. Further, the ballast capacity and combination are selected according to the connected ballast loads. There are three steps are used here, which are most frequently used in controllers in the process industry [7].

Proportional: the error is multiplied by a gain Kp. A very high gain may cause instability, and a very low gain may cause the system to drift away.

Integral: the integral of the error is taken and multiplied by a gain Ki. The gain can be adjusted to drive the error to zero in the required time. A too high gain may cause oscillations and a too low gain may result in a sluggish response.

Derivative: The derivative of the error is multiplied by a gain Kd. Again, if the gain is too high the system may oscillate and if the gain is too low the response may be sluggish.

Ballast load

The pin numbers 6 to 30 on the microcontroller are used for Ballast switching and the exact number depends upon the project capacity, single or three phase and commercially available electrical components such as heating elements and TRIACS. Then, any capacity of load can be selected accurate up to the smallest heating element capacity by using different combinations of connected heating elements. For example, ballast loads used in a 10 kW project are 0.125, 0.250, 0.500, 1.000, 2.000, 3.000, 4.000, 4.000 kilowatts. Load levels in 125 watts steps from 0 to 14.875 kW can be selected here. The maximum capacity of a single load is limited to 5 kW due to constraints in commercially available heating loads and TRIACS capacity.

Protection

Hydro power plants should run 24 hours per day throughout the year. During the lightening period a lot of surge comes through the distribution lines. The situation is even more severe when the distribution lines pass through hill tops and bare lands. The most powerful part of the surge passes through the air gap type surge protectors which are installed in distribution panels and lines. The remaining part of surge may be harmful to the highly sensitive electronics components in the controller. Therefore highly sensitive fast recovery surge protection system of zener diode type is fixed to the controller. Further high voltage and DC low voltage sides are electrically isolated with the use of opto-couplers.

In case a hydro power project goes out of control due to an unexpected cause, the voltage and frequency doubles within few seconds and all the connected electro- mechanical items get damaged. Controller over/under voltage or frequency, consumer's line is disconnected within 5 seconds as the first step. Further an output signal is issued to shut down the turbine. Unfortunately, presently commissioned locally manufactured hydro power plants do not have emergency shut-off mechanisms such as jet deflector or motor powered valves, thus making this output unusable as is the case with most of the turbines.

Results and Discussion

Up to now fifteen of these controllers have been installed and the first one was commissioned in 2009 in Lenarkwatta village hydro power project, Godakawela. The rest of the controllers were mainly installed in place of damaged phase angle type controllers and it has been observed that technical failures and maintenance costs have thereby significantly decreased. By installing this controller, ECS could minimise the technical faults and maintenance cost while it also very much helps raise hope on the hydro power project.

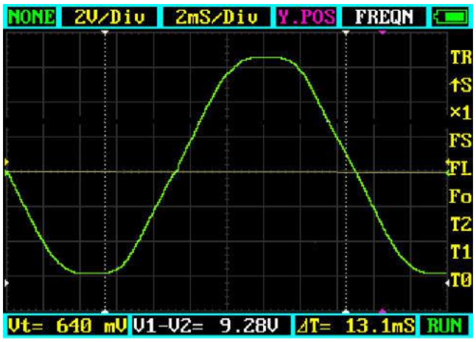


Figure 12: Wave form of a Multiple, loads zero crossin point switching controller

Figure 12 shows the output wave form of the distribution line. The ballast also receives the same wave form and the only difference is randomly OFF and ON and zero crossing points.

Lenarkwatta VHP, Godakawela (20kW), Galpothuyaya VHP, Kalawana (18kW) and Illumbakanda VHP, Kalawana (11kW) were closely monitored over four years with this controller and there were no technical failures that were discussed here. So consummers of those projects get electricity throughout the year and a significant portion of monthly electricity bill could be saved.

Conclusions

The main objective was development of a highly reliable controller to entrust to the indigenous hydro power technology. The highest components of the maintenance cost of a hydro power project are travelling cost (multiple times of travel from Colombo to rural areas), waste of time and damages to other component of the system (generator, capacitors, bearing and switch gears) due to poor control technologies. The "Multiple loads, zero crossing switching controller" has proved to significantly reduce the maintenance cost. Successful introduction of this controlling technology can reduce the maintenance cost, improve reliance on naturally available energy sources and at the same time reduce the load on the highly subsidized national grid.

Acknowledgements

The field level testing was done in Lenarkwatta village Hydro power project, Masimbula Godakawela. I would acknowledge the Lenarkwatta electricity consumer society for giving this opportunity. Further I extend my sincere thanks to Mr. P.C Hettiarachchi, one of the pioneers of Sri Lanka hydro power sector who encouraged me until the final solution was accomplished despite hundreds of times of failures.

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Potential, Viability and Availability of Quality Paddy straw for Electricity Generation in Sri Lanka

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Abstract

The exploitation of paddy straw as renewable energy has gained momentum since the present energy crisis and global warming threat. Paddy straw has low heating value, low bulk density and significant amount of alkali and alkaline compounds. This makes it difficult to handle, transport and store efficiently hence limiting the commercial use of paddy straw. Utilization of Paddy straw for power generation as a renewable energy source has not attracted up to now. This paper presents an approach in estimating the paddy straw availability, viability and potential for electricity generation in Sri Lanka. Assuming that 20% of paddy straw produced is available for power generation, the energy potential has been forecasted upto the year 2020 and it cannot be expected to continue indefinitely. With the present 941,000 hectares of paddy cultivation, 3,652,000 metric tonnes of paddy production and 6,416,000 metric tonnes of annual paddy straw production, more than 82 MW of electricity generation potential is available in Sri Lanka. However, seasonal variation of paddy straw availability constrains a steady, year-round fuel supply from this source in Sri Lanka. Further, the production potential of paddy depends on several factors including population growth, land use pattern, productivity, per-capita rice consumption (which could change with life style) and the government policy. Follow-up article with greater focus on above five factors as well as on the technologies, practical aspects and overall analyses of project feasibility of power production with more detailed analysis would be presented.

Keywords: Paddy straw, Electricity generation, Potential

Introduction

Sri Lanka is an agricultural country and it has a considerable percentage of agricultural lands. Paddy is the major domesticated crop and is mainly cultivated as a wetland crop within this country. The total land area devoted for paddy is estimated to be about 941,000 ha at present [1]. There are two cultivation seasons namely; Maha and Yala which are synonymous with two monsoons. Rain in Maha season received during "North-East monsoon" from November to February and rains in Yala season is effective during the period from May to end of September. Paddy seasons are mainly determined by these two wind patterns within Sri Lanka.

However, the whole area devoted for paddy is not being cultivated due to a number of reasons such as shortage of water during the seasons, prevailing unsettled conditions on the ground, etc. As a solution for shortage of water there are several number of irrigation schemes that have been introduced to the country.

Energy sources in Sri Lanka consist primarily of hydro, coal, fossil fuel and biomass. Wood fuels (firewood and charcoal) comprise the predominant source of energy for rural populations in developing countries including Sri Lanka.

Non-Conventional Renewable Energy (NCRE) include small-scale hydropower, biomass including dendro power, biogas and waste, solar power and wind power. These are the leading sustainable, non-conventional forms of renewable energy promoted in Sri Lanka for electricity generation into the grid.

Time to time Sri Lanka National Energy Policy is revised and latest national energy policy gives better environment for development of renewable energy opportunities in the country. The Government will endeavour to reach minimum level of 10% of electrical energy supplied to the grid to be from NCRE by a process of facilitation, including access to green funding such as Clean Development Mechanism (CDM). The target year to reach this level of NCRE penetration is 2015.

Present (year 2014) contribution of NCRE is 7% and the development of small hydro and wind alone shows that the 10% target by 2015 is really achievable [2].

Necessary incentives will be provided and access to green funding including CDM will be facilitated to develop NCRE resources to ensure their contribution to the energy supply in special situations, even if their economic viability is marginal. Biomass-based energy projects will be developed in areas where land resources are available, enabling new industrial activities in such areas, emphasising on creating rural income generation avenues.

Commercial development of biomass will be encouraged and facilitated as a new rural industry allowing the farmers to engage in collecting and selling straw and to participate in the mainstream economic activity by supplying electricity to urban load centres [2].

The total paddy production increased rapidly over the last 58 years and it has reached 3,652,000 metric tonnes in 2009[3]. Paddy straw has an enormous renewable energy potential in Sri Lanka.

The provision of straw energy utilization in the country would result in the mitigation of Green House Gas (GHG) emission from fossil fuel savings. However, to tap this potential renewable source, several hurdles must be overcome. There are various conversion routes to use paddy straw as an energy source. Because after paddy harvesting, the straw is usually characterized by low moisture content, the direct combustion process seems to be the favourable path for utilization. However the overall utilization efficiency of traditional furnaces is about 10-34% and improved design can go up to about 50% [4].

The lower heating value (LHV) of the paddy straw has been reported by various studies in the range from 10.9 MJ/kg [5] to 16.0MJ/kg [6] which leads the paddy straw biomass to be an increasingly attractive method of generating electricity.

Paddy straw based power generation can serve Sri Lanka in many ways. Primarily, it provides electricity (the energy generation tool) and serves as a way to dispose of agricultural waste (environmental management tool). Availability of tonnes of fly ash and bottom ash can be added back to the field itself because it returns minerals to the soil or fly ash can be used in the cement industry to make Portland pozzolana cement, composite cement and asbestos industry and bottom ash can be used to make cement blocks and bricks respectively. In addition, steam, a by-product of power generation, can be used for thermal drying and heating applications. Therefore, the main objective of this study was to investigate the potential, viability and availability of paddy straw for power generation in Sri Lanka.

At present there is a national policy effecting use of paddy straw for other uses (including energy) as farmers are required to return all the straws in to the paddy field in order to qualify for fertilizes subsidy. As regards energy recycling, it is better to use paddy straw first as an animal feed and then use the animal wastes as fertilizer or in alternative processes that produce energy, such as biogas and slurry or manure can be used as organic fertilizer. A disadvantage of adding straw is that it may carry over weed, pest and diseases to the next crop and reduce effectiveness of fertilizer. It also has increased atmospheric emission of methane and nitrogenous compounds from the flooded field. However, a recent research study carried out by University of Peradeniya [8], has indicated that around 15% of straw generated is sufficient to be returned to the field and that excessive addition could affect the yield adversely and also resulting environment effects due to GHG emissions. Another alternative is to remove the straw for energy utilization. This method has similar in effectiveness to burning in weed and disease control because material is removed from the field.

Paddy straw availability in Sri Lanka

Paddy straw is the most important agriculture residue from paddy production. Paddy straw is produced at the paddy field itself when paddy is harvested. Paddy straw is not utilised to its full potential and it is common during the harvesting season to see farmers burning huge quantities of straw.

Burning of paddy straw and stubble is a traditional practice throughout the Asian region. There are several reasons for this and their importance varies between areas within the region. It reduces the incidence of pests and diseases, facilitates soil preparation for a second rice crop and it returns minerals to the soil. Although burning leads to organic matter loss, it is quick and overcomes the many problems associated with slow decomposition of straw.

The paddy straw production per district can be taken directly from the district-wise paddy production figures, as there is no considerable transfer of paddy straw between districts. It is estimated that only 50% of the rice production in the country enters the commercial market, and the other 50% remains in the field. The availability of paddy straw mainly depends on the paddy production and the Residue to Product Ratio. The total paddy production in the year 2009 was 3,652,000 metric tonnes [3]. There has been significant growth in the paddy sector after the war in Sri Lanka. Thus it is seen that paddy straw, an important material, is freely available twice a year, during the harvesting periods.

The total paddy production increases rapidly over the last 58 years in Sri Lanka. Data are available from 1952.

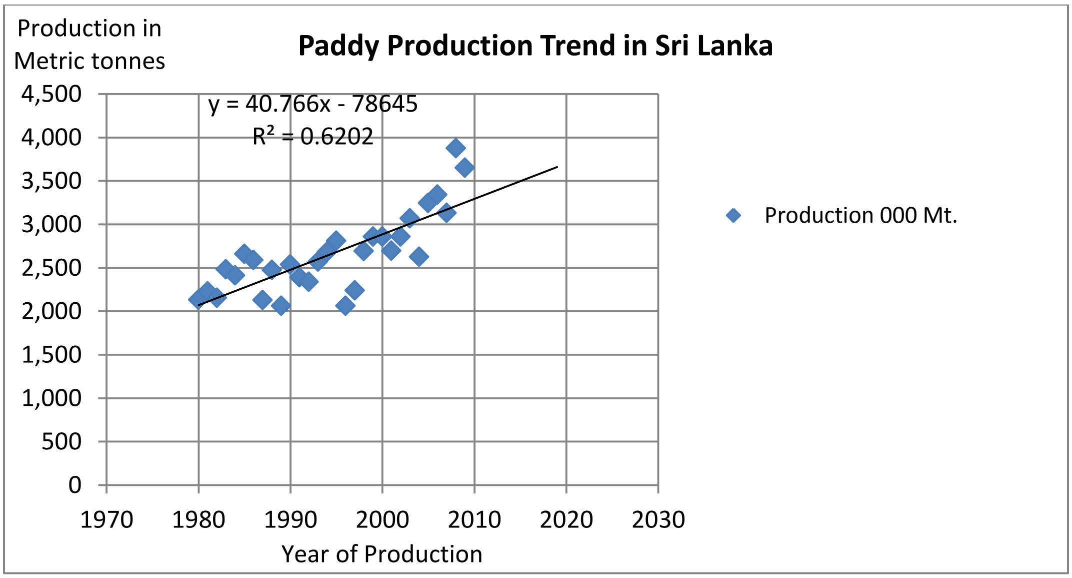

Figure 1: Paddy production trend in Sri Lanka

As per the data, from 1980 to 1994 a lower rate and subsequent 15 years a higher rate of increase could be seen Therefore first trend from 1980 to 1994 is shown in Figure 2.

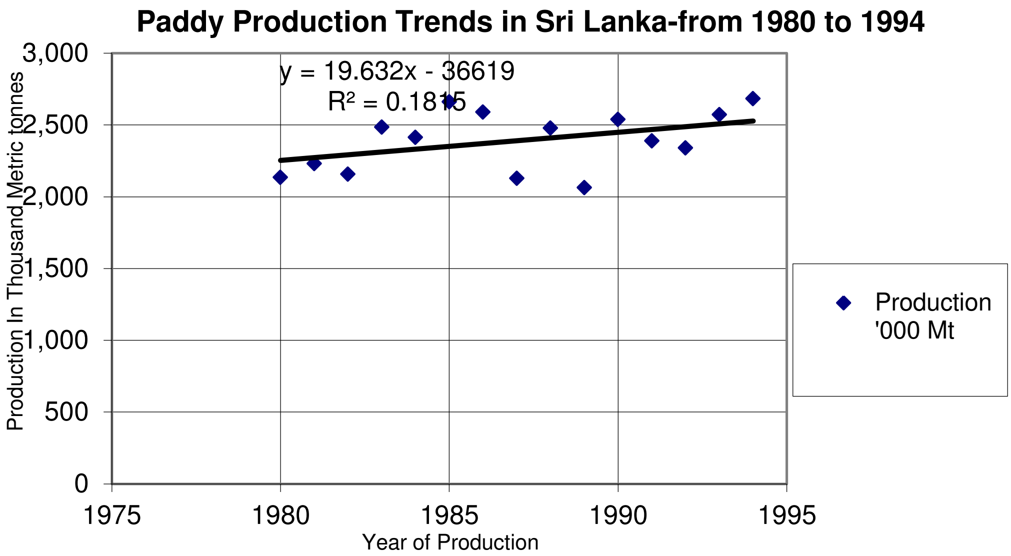

Figure 2: Paddy production trend in Sri Lanka-1980-1994

For this study, paddy production data of last 15 years have been considered because it is recommended that at least 15 pairs of data be collected for scatter diagram. Median method is used and confidence level of 95% for a definite positive correlation. It was found that the trend of paddy production could be approximated to a linear trend (see Figure 3) with the following least square regression fit for its time variation:

Y=88.96X-17516 [equation (1)]

R^2=0.690

Where Y is the paddy production in thousand metric tons and X is the time in years.

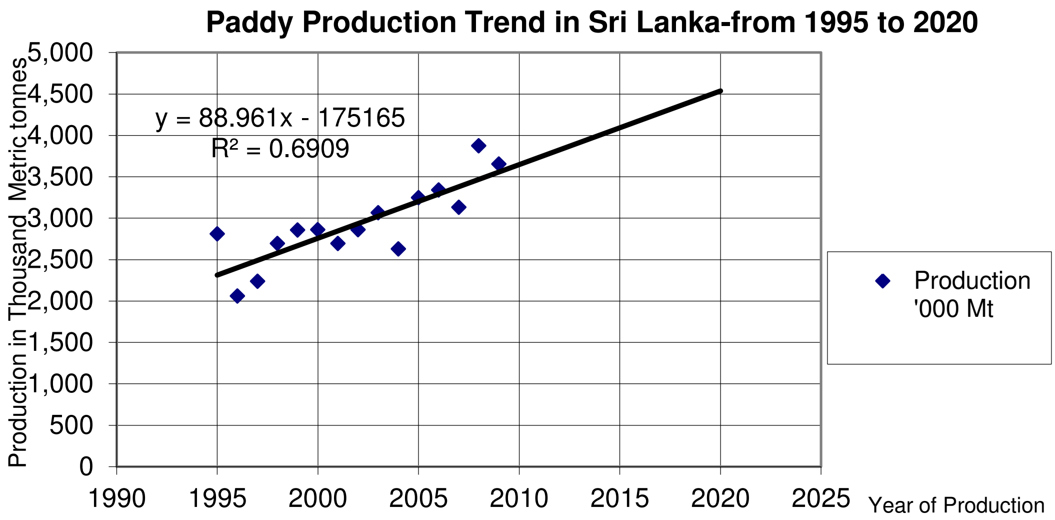

Figure 3: Paddy production trend in Sri Lanka -From 1995 to 2009 and forecasted upto 2020

Potential of Paddy straw for Power Generation

Electrical energy is essential for the economic development of any country. Industrial development is impossible without a reliable and an economical supply of electrical energy. At present the demand of electrical energy in Sri Lanka is increasing at a rate of about 7% per year [7]. This could be expected to increase further if there is an increase in the rate of economic development.

Assuming that 20% of paddy straw produced is available for power generation, the energy potential has been forecasted up to the year 2020 using equation (1) that derived early and shown in table 1 below.

Deriving Straw to Paddy Ratio (SPR)

There are two methods for estimating paddy straw generated in the field. One is use of SPR, which is more reliable and depends on the grain yield. Also grain yield data are more accurately available through crop/rice statistics. The other is multiplying the amount of paddy straw generated (in tonnes) per hectare with total area of rice cultivated. Here in this case crop density would vary considerably over seeding practices across various regions. Thus it is quite unpredictable and difficult to identify. The first method is used in the current research as it is more reliable and represents the ground level reality. Since the actual measurement of straw generation is not possible practically within this paper, literature survey was carried out to ascertain the most suitable value to be used for calculating paddy straw residues.

According to the UNEP-guideline for waste characterization and quantification, the SPR value for straw is 1.5.

According to literature the SPR value for paddy straw range from 0.416 to 3.089. These values have been cited in research papers and reports from around the country. Available literature shows a considerable change in SPR, the average of the above which is 1.758 has been taken as the SPR for the present study.

Lower Heating Value (LHV) of paddy straw and its moisture content

The LHV is an important parameter that is required in the analysis of energy potential from available paddy straw. This would be identified through ultimate analysis. The LHV of the paddy straw has been reported by various studies in the range from 10.9 MJ/kg [5] to 16.0MJ/kg [6] which leads the paddy straw biomass to be an increasingly attractive method of generating electricity.

Alternative uses for paddy straw

Paddy straw is the property of the farmer and he determines its utilization. Several recent reviews (e.g. Han, 1978; Devendra, 1982; Castillo, 1983) have considered the alternative uses of paddy straw. Consequently, these will only be dealt with briefly here. The more important uses of rice straw can be listed as:

(i) Burning
(ii) Fertilizer
(iii) Mulch for vegetable production
(iv) Substrate for mushroom growth
(v) Bedding for livestock and poultry
(vi) Fibre for paper manufacture
(vii) Thatching roofs of houses
(viii) Fuel to produce heat
(ix) Feed for livestock
(x) Packing material(transporting two pot cook stoves etc)
(xi) packing of coffin
(xii) production of biogas

In this calculation, SPR is taken as 1.757, LHV as 13.46 MJ/kg (Average of the range) and conversion efficiency as 15%.

Table 1: Paddy straw based biomass energy potential in Sri Lanka

Cultivation Year	Paddy Production '000 MTs.	20% of Annual Paddy straw production in '000MTs	Available energy potential in GJ	Annual Average Energy in GWh	Nominal Plant Rating in MW
1980	2,134	750.1	10096933.9	420.7	48.1
1981	2,229	783.5	10546422.6	439.4	50.2
1982	2,156	757.9	10201026.0	425.0	48.6
1983	2,484	873.2	11752944.7	489.7	56.0
1984	2,413	848.2	11417011.0	475.7	54.4
1985	2,661	935.4	12590412.9	524.6	60.0
1986	2,588	909.7	12245016.4	510.2	58.3
1987	2,127	747.7	10063813.7	419.3	47.9
1988	2,477	870.7	11719824.4	488.3	55.8
1989	2,063	725.2	9761000.3	406.7	46.5
1990	2,538	892.2	12008443.4	500.4	57.2
1991	2,389	839.8	11303456.0	471.0	53.8
1992	2,340	822.6	11071614.5	461.3	52.7
1993	2,570	903.4	12159850.1	506.7	57.9
1994	2,683	943.1	12694505.0	528.9	60.5
1995	2,810	987.8	13295400.4	554.0	63.3
1996	2,061	724.5	9751537.4	406.3	46.4
1997	2,239	787.1	10593737.1	441.4	50.4
1998	2,692	946.3	12737088.2	530.7	60.7
1999	2,857	1004.3	13517778.9	563.2	64.4
2000	2,860	1005.3	13531973.3	563.8	64.4
2001	2,695	947.3	12751282.5	531.3	60.7
2002	2,860	1005.3	13531973.3	563.8	64.4
2003	3,067	1078.1	14511385.4	604.6	69.1
2004	2,628	923.8	12434274.8	518.1	59.2
2005	3,246	1141.0	15358316.6	639.9	73.1
2006	3,341	1174.4	15807805.2	658.7	75.3
2007	3,131	1100.6	14814198.8	617.3	70.5
2008	3,875	1362.1	18334404.4	763.9	87.3
2009	3,652	1283.8	17279289.0	720.0	82.3
2010	**3647**	**1281.9**	**17253786.4**	**718.9**	**82.2**
2011	3736	1313.1	17674701.8	736.4	84.2
2012	3825	1344.4	18095617.1	754.0	86.2
2013	3913	1375.7	18516532.5	771.5	88.2
2014	4002	1406.9	18937447.8	789.1	90.2
2015	**4091**	**1438.2**	**19358363.1**	**806.6**	**92.2**
2016	4180	1469.5	19779278.5	824.1	94.2
2017	4269	1500.8	20200193.8	841.7	96.2
2018	4358	1532.0	20621109.2	859.2	98.2
2019	4447	1563.3	21042024.5	876.8	100.2
2020	**4536**	**1594.6**	**21462939.9**	**894.3**	**102.2**
2021	4625	1625.8	21883855.2	911.8	104.2
2022	4714	1657.1	22304770.5	929.4	106.2
2023	4803	1688.4	22725685.9	946.9	108.2
2024	4892	1719.7	23146601.2	964.4	110.2
2025	**4981**	**1750.9**	**23567516.6**	**982.0**	**112.2**

Paddy Straw Quality

Sizing

This involves the cutting of Paddy straw into smaller sizes to improve boiler efficiency. Dried paddy straws with length range from 35-70cm are cut in to sizes less than 25 (10-5, 5-2, or <2 mm) at the outlet by the blade of the rotating knife holder of a homemade machine (grinding and hammer mills). Preparation of rice straws for co-firing in a boiler requires reducing the material to smaller size to increase the energy conversion efficiency and combustion performance (Annamala, Wooldridge, 2001). Large particles of biomass feedstock such as wood chips could provide a boiler efficiency of about 70% while the small size biomass such as rice husk, cut straw and sawdust could provide boiler efficiency of 75% (Omori, 2006).

It is usually not practical and not necessary to bring the biomass feedstock to the same size and shape as coal. However large and spherical biomass particles cause challenges for fuel conversion efficiency such sizes would cause an incomplete combustion of biomass.

Fine sized straws (5-2 mm) improve the combustion behaviour (Strehler and Stuetzle, 1987). However, large sizes (10-5 mm) of biomass do not adversely affect the combustion performance.

This technology can be commercially used and feasible in Sri Lanka at the paddy generating point itself using manually operated simple straw cutting or sizing machine.

Palletizing

This is a compacting process that produces homogenous fuel with high energy density into different shapes examples square, rectangle and cube with dimension of 50x50x50 mm^3 (Loo Van et al., 2004a). It involves the following steps: drying, milling, conditioning, actual pelletizing and cooling of biomass.

An important advantage of pelletizing is that, it addresses the issue of low bulk density of biomass which has an impact on transportation cost as well as the required storage space in comparison with other biomass material and it can restrict the co-firing ratio due to limited capacity of boiler impact system.

The moisture content of the raw material before entering the pellet press must be 12-17 % (w.b) and it is essential not to exceed these values (European Biomass Association, 2000).

Transport

Transport of bailed straw can be up to 50% less costly than transportation of loose material and about 1% cheaper than that of wood chips (Caldwell et al., 1988). However, this method requires good transport system to carry the baled rice straw from the field to the power plant or storage. It is also dependant on weather and soil conditions of the field. This technique can be carried out efficiently in many developing countries with simple transport devices like bullock cart which does not consume fossil fuel.

Conclusions

The following conclusion could be drawn from the research

a) The production potential of paddy depends on several factors including Population growth, land use pattern, productivity, per-capita rice consumption (which could change with life style) and government policy. Those above five factors are not considered in this paper.

b) As per the data, from 1980 to 1994 (first 15 years) a lower rate and subsequent 15years a higher rate of increase could be seen.

c) Definitely there is potential for power generation from paddy straw in Sri Lanka.

d) Energy crisis in the world is a rapid escalating global issue today. Since hydrocarbon reserves in the globe are being exhausted the need of discovering alternative sustainable energy solutions are being considered, researched and attempted by all countries.

e) Paddy straw could be used with the current power technologies in Sri Lanka to replace fossil fuels to reduce sulphur dioxide and GHG emissions as well as prevent pollution from rice straw open burning and further studies should be done.

f) Compression of rice straw to homogenous fuel, improves the energy conversion efficiency and combustion performance of the rice straw. It also improves the bulk density of the straw. Thus, reducing the associated cost of transportation, handling, and storage.

g) Detail economic consideration and analysis of these technologies are not mentioned in this paper. However, the discussion from this paper could be used for further work involving economic analysis and could be applied for research on other agricultural residues which is beyond the scope of this paper.

h) For the sustainable utilization of biomass energy in Sri Lanka, Sri Lankan research institutions should be encouraged and supported to research further into biomass areas and support for Sri Lankan innovators.

i) Follow up article with greater focus on the population growth, land use pattern, productivity, per capita rice consumption (which could change with life style) and government policy with more detailed analysis would be presented.

j) A significant saving on primary energy importations could be gained for the country from paddy straw based power generation through combustion systems. The overall analysis need to be followed by the societal impact assessment which can be viewed in the future work.

Future Plan

1. An approach that may increase the use of paddy straw energy in the short-term is to burn it, mix with coal in power generation plant and in cement mill, a process known as "co-firing". Find out the best proportion of paddy straw blend with coal in a boiler.
2. Overall analyses of using rice straw residue for power generation in Sri Lanka-project Feasibility Commercial feasibility of utilizing rice straw in power generation
3. Experimental investigation of ash deposit shedding in a straw-fired boiler in Sri Lanka
4. Fuel Blending-Existing wood fired boilers can likely fire rice straw with few difficulties other than fuel handling
   Find out the best proportion of paddy straw blend with wood in a existing wood fired boilers.
5. Future studies should be conducted to find economical methods of producing electricity in order to compete with fossil fuel.
6. Cross learning across the region and dissemination of results of the project through networks, across the region, as well as at international level.
7. Follow up article with greater focus on the technologies and practical aspects of power production with more detailed analysis would be presented.

Discussion

Present contribution (year 2014) of NCRE is 7% and the development of small hydro and wind along shows that the 10% target by 2015 is really achievable [2].

Initiatives to introduce paddy straw as grid connected electricity energy source has not yet made a significant impact to Sri Lankan energy sector, though there are 941,000 hectares of rice cultivation, 3,652,000 metric tonnes of paddy production and 1,283,800 metric tonnes of annual paddy straw production.

In this analysis, it is found that there is more than 17,279 TJ annual energy potential available in Sri Lanka and subsequently more than 82 MW of power generation potential using paddy straw. However, it is not investigated that population growth, land use pattern, productivity, per capita rice consumption (which could change with life style), government policy and the effect of time variation of paddy production (seasonal effect) to the plant capacity estimations in this study.

The amount of paddy straw produced from paddy depends on several factors such as paddy variety, fertilizer, season, and harvesting practices etc. Presently most of the straw produced are either burned in the field or used as animal feed. A portion also goes to the paper making industry. Paddy straw also plays a vital role as a candidate raw material for biogas production systems which has been developed by various local institutions.

According to literature the SPR value for paddy straw range from 0.416 to 3.089. These values have been cited in research papers and reports from around the country. Available literature shows a considerable change in SPR, the average of the above which is 1.758 has been taken as the SPR for the present study. Actual values of these parameters for different province are important for accurate estimation of the potential. In order to study the impact of variation of such parameters, sensitivity analysis could also be done separately.

Fuel Handling System Modification-Existing Sri Lanka biomass power plant fuel handling systems need modification to use rice straw. Such modification would in general include addition of bale storage space in the fuel yard, added bale moving equipment, grinding equipment, and extra equipment to meter straw into the primary fuel stream. Densification (cubing) can be used to improve handling. Dust suppression would be needed where straw grinding is employed. In addition, grinders and other equipment can be powered with the electricity from the plant itself.

Furthermore, Teaching of biomass technology is being done currently at some courses in the Universities. To some extent there is awareness of the existence of the process and its basics. However, the teaching may have to be updated to include details of potential benefits (the full spectrum of possibilities and how each can be realised) and its world wide applications (not just in China, Brazil, India, and Thailand as mostly the case in teaching) along with management aspects. Technical level programmes should also be included with appliance manufacturing, fabrication and maintenance. Continuing education courses may be initiated for those who can potentially benefit from the technology.

Universities should be encouraged to take up research and development work to support biomass energy and its power generation. Wide range of disciplines from Sociology to Engineering and Science to Town can effectively support the integration of bio energy in to current practice. In countries such as India and China Universities and Research Organizations carry out a wide range of R and D activities to support biomass systems with the support of both government and non-governmental sector. The emphasis in these countries is on systems appropriate to rural settings.

It is important that a credit scheme for those who will need the initial capital to invest in technologies for utilization of bio energy resource potential, be provided.

At present there is a national policy effecting use of paddy straw for other uses (including energy) as farmers are required to return all the straws in to the paddy field in order to qualify for fertilizes subsidy.

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Abréviations

NCRE - Non-Conventional Renewable Energy
GHG -Green House Gas
CDM -Clean Development Mechanism
CV -Calorific Value
SPR -Straw to Paddy Ratio

Review of conversion technologies of waste PET into useful energy

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Abstract

Poly Ethylene Terephthalate (PET) is a Polymer which is utilized in a larger scale for various domestic and industrial applications. As a result of the expansion of consumption, the waste PET has become a solid waste as well as an environmental pollutant because, almost all the packaging of fast moving consumer goods are PET bottles or containers. This paper presents a review of existing state of research and technologies in converting the waste PET into useful energy outcomes. Although it is possible to recycle PET and use them to produce new products especially in developing countries, recycling of PET is not done successfully. In such countries, still the most common methods of dealing with waste PET are using them for landfill and incineration. Using disposed waste PET for land fill can cause severe environmental issues because they are not bio-degradable. Incineration also is not a suitable solution because, it will cause emissions of greenhouse gases and toxic gases to the atmosphere. According to the existing research, different technologies like aminolysis of waste PET, glycolysis of waste PET are available in order to make useful output from PET waste. However, one of more sustainable solution to deal with waste PET is to convert waste PET into liquid or gaseous fuel. The technologies like pyrolysis and gasification can be used to produce fuel from PET waste. But, most of the research findings have not been widely used as mass scale applications. Therefore, the objective of this paper is extending some analysis over existing research findings in order to identify a better technique which has future research potential for conversion of waste PET into useful energy.

Keywords: Poly Ethylene Terephthalate (PET), solid waste, aminolysis, glycolysis, fuel from PET waste, useful energy

Introduction

During the last few decades, the technology has developed by leaps and bounds, and plastics have replaced most of the materials in household and engineering applications. Plastics have become an essential component of almost every product from simple toys to synthetic body parts. The main reasons for this revolution are,possibility of plastic production in large quantities with the expanded production of fossil fuels and their availabilityof wide range of properties. Poly Ethylene Terephthalate (PET) is one such plastic material which is utilized in a variety of domestic and industrial applications.

Polyethylene Terephthalate (PET) is a polymer, which is produced by condensation polymerization of Terephthalic acid and Ethylene glycol. In the industrial scale, PET is usually synthesized using ester-exchange method where, Dimethyl terephthalate is reacted with Ethylene glycol. Figure 1 illustrates the repeating unit of PET polymer[1].

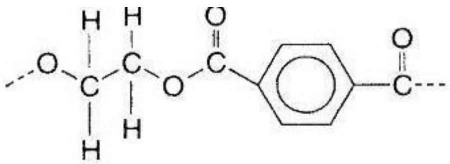

Figure 1: Repeating unit of PET[1]

The exact properties of PET depend on various factors such as molecular weight, molecular structure, presence of impurities and other factors. PET can be classified into several categories based on physical properties. As such, PET can be classified as low-viscosity PET and high-viscosity PETbased on viscosity. Low-viscosity PET is used in various products like apparel fiber, bottles and photographic films and high-viscosity PET is used in seat belts and tire-cords. PET is a thermoplastic material and can be used in the form of fiber, sheet or film. Polyethylene Terephthalate has a variety of applications including synthetic fiber, beverage bottles, food packaging, containers for toiletries, cosmetics and pharmaceuticals, molding resins, X-ray and other photographic films, magnetic tape, electrical insulation and printing sheets. Among those, the most common applications are utilization of PET as a packaging material, and as disposable water bottles[2].

In consequence of the main source of PET is crude oil, the extensive consumption of this type of plastic has contributed the rapid diminishing of non-conventional energy sources in the world. It has been estimated that, 25% of PET produced every year all over the world, are dumped after consumption in various ways. These actual quantities are in millionsof tons annually[3]. Therefore, it is true that, huge energy content in the form of crude oil is wasted annually that is used to make plastics in the form of PET. This is why the techniques to recover this waste PET as a useful energy output becomes so valuable. In other words,the depleting rate of non-renewable energy sources like fossil fuels can be reduced into certain extent with these kinds of approaches of waste energy recovery. Approximately 3 million tons of PET are produced annually to make disposable bottles[4]. Those water bottles are usually designed to be disposed after using once. Therefore,used PET bottles are a significant component in municipal waste as well as can be observed in any waste collection bin as a common type of garbage.Although it is possible to recycle PET and use them to produce new products, recycling of PET is not a viable solution especially for developing countries because it a very expensive process[4]. The most common methods of dealing with waste PET bottles in developing countries are using them for landfilling and incineration[4]. Using disposed PET bottles for landfilling can cause severe environmental issues because they are not bio-degradable. Incineration is also not a suitable solution because, it will cause emissions of greenhouse gases like CO2 and toxic gases like SO2. In addition, incineration of PET will produce very hard and solid complex substances of Terephthalic acid and benzoic acid, which are not bio-degradable[4]. Therefore, it is necessary to implement more sustainable solutions in order to deal with PET waste which will be suitable for developing countries like Sri Lanka.

In existing literature, many research are carried out to make use of waste PET inalternative ways rather than disposing them to environment. The Aminolysis of PET waste can be used as a corrosion inhibitor in Carbon steel forhydrochloric acid (HCl). This has been experimentally shown by recyclingPET waste using Mono ethanol amine (MEA), sodium acetate and HCl[5]. The results were found using weight loss, open circuit potential and potentio-dynamic polarization measurements[5]. According tothose results, it has been found that PHETA[poly(bis(2-hydroxy ethylene)terephthalamide] is a good inhibitor for Carbon Steel in HCl medium and the efficiency of the inhibitor will be increased with the increasing concentration of PHETA[5]. However, the efficiency of the inhibitor decreases with the increment of temperature and that concludes the protective film created by these compounds in Carbon Steel is less stable at higher temperatures[5].

PET waste dumped in soilcan be pretreated with ultra violet rays (UV), heat, nitric acid and then introduced with micro-organism named*Pseudomonas sp*[6].Such treated samples displayed significant changes on the surfacesmorphology of PET observed using an SEM microscope[6]. The *Pseudomonas sp* shows tohave the ability toadsorb over the PET surface and accelerate the PET degradation process[6]. Experimental analysis carried out for a period of one month, revealed that, using micro-organisms to accelerate the degradation of PET can be used as an effective method to minimize the environmental pollution caused by waste PET landfilling[6], [7].

PET waste can be used to produce Polyester Polyol for coating applications for Mild Steel. In this process, initially the PET was put under the glycolysis process using poly propylene glycol. Secondary reaction was the trans-esterification process carried out using Castor or Jatropha oil[8]. Then the produced polyester polyol combined with Melamine Formaldehyde is coated on mild steel. The research pointed out that the coating properties were depended on the amount of PET used for glycolysis and the type of oil used for the trans-esterification[8]. When the percentage of PET was increased, properties of mild steel such as, corrosion resistance, MEK double rub resistance, pencil hardness, and solvent and chemical resistance were increased. Coating system which was based on Castor oil having a 10% PET showed the best performance[8].

Waste PET is possible to use as an aggregate in Concrete too. According to the past research, three aggregate types prepared from PET waste were used which are namely the coarse flakes (PC), fine fraction (PF) and the plastic pellets (PP)[9]. The result showed that the development of compressive strength of concrete containing all types of PET aggregates was similar to conventional concrete[9]. However, when the early compressive strength gain (0 to 7 days) was compared to the compressive strength determined after 91 days of curing, the compressive strength in concrete containing PET aggregates was higher than that of the conventional concrete[9]. Furthermore, the incorporation of PET aggregate in concrete increasedits' toughness behavior[9]. For a given amount of PET addition, the toughness behavior was increased in themanner ofPC > PF > PP respectively, which indicates that the addition of large flake PET aggregates can have more effect on the improvement of the toughness behavior of resulting concrete[9].

Two novel additive materials, namely Thin Liquid Polyol PET (TLPP) and Viscous Polyol PET(VPP) have been derived chemically from PET bottle wastes and used as additive within the asphalt in order to use as a roadway pavement construction material. According to the results of the research executed with TLPP and VPP modified asphalts, they can be recommended to use in regions with low temperatures and high humidity as a construction material to improve the roadway performance[10].

Eventhoughexisting literature suggests several alternative approaches and different techniques of converting waste PET into some kind of useful output, almost all of those methods have not been able to make a significant effect towards the non-renewable energy wastage happens in the energy lifecycle in the world. However, it can be observed in the existing literature that, a more sustainable solution to deal with PET waste is to convert waste PET into liquid or gaseous fuel. This is also useful in aspects of sustainable energy, because this fuel will act as an alternative for petroleum fuel. Methods like pyrolysis and gasification can be used to produce fuel from PET waste. Therefore, this research paper will converge and summarize the most recent existing research outcomes regarding the waste PET conversion into useful fuels.

Review and Discussion

Various research studiescan be found regarding conversion of PET into liquid fuel and useful energy. In one of such experiment, pellets of PET obtained from waste water bottles had been mixed with catalysts with a catalyst to sample ratio of 2, and heated at 405 0C for 20 minutes to convert PET into liquid fuels through catalytic thermal conversion[4]. According to past research Ca(OH)2, Ni(OH)2 and Fe2O3 can be used as catalysts for this conversion[4]. The resulting product had consisted of 14.25% liquid fuel, 12.5% volatile gases, 51.5% solid residue and 21.75% water[4]. The yield of fuel from pure PET is low due to high Oxygen percentage in PET[4]. However, it has been experimentally shown that the yield of fuel can be increased by mixing PET with other plastics like LDPE. The liquid fuel obtained from this experiment had been a highly flammable, yellowish liquid with a density of 0.9 g/ml and a boiling point of 65.96 0C, and the solid residue had been an ash coloured crystalline powder[4]. The fuel samples obtained in this experiment had been analyzed using gas chromatograph/mass spectrophotometer (GC/MS). According to the obtained results, the liquid fuel consisted of saturated and unsaturated hydrocarbons containing 6 to 27 Carbon atoms as well as, some aromatic compounds like Benzene, Benzene ethanamine etc.[4]. The GC/MS chromatogram and differential scanning calorimeter (DSC) curve which were obtained for this fuel in the cited research experiment have been given by figure 2 and figure 3 respectively[4].

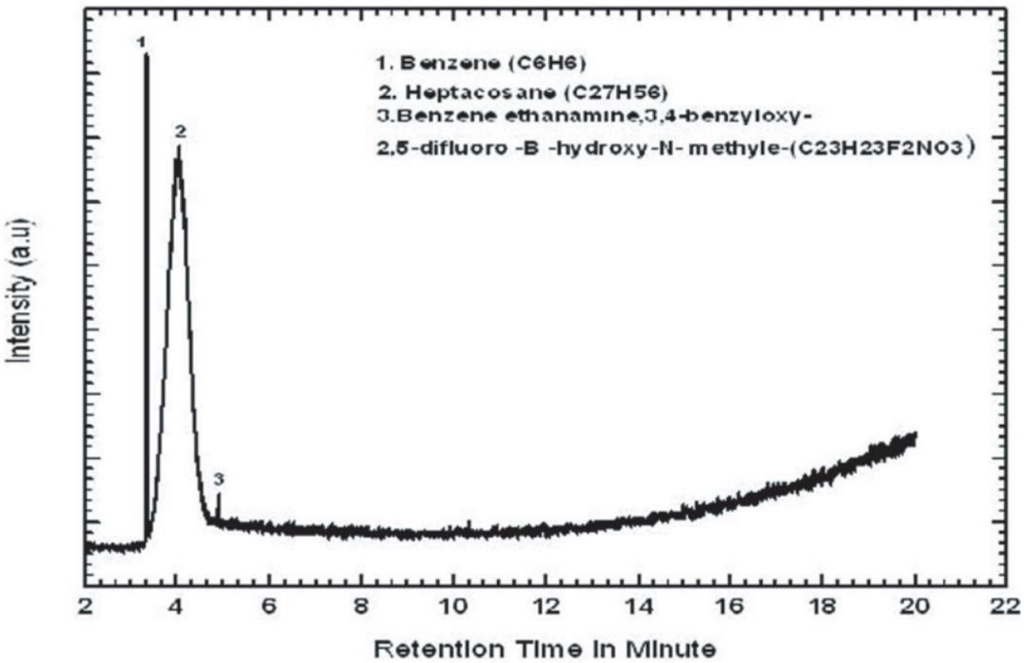

Figure 2: GC/MS chromatogram for fuel produced using PET[4]

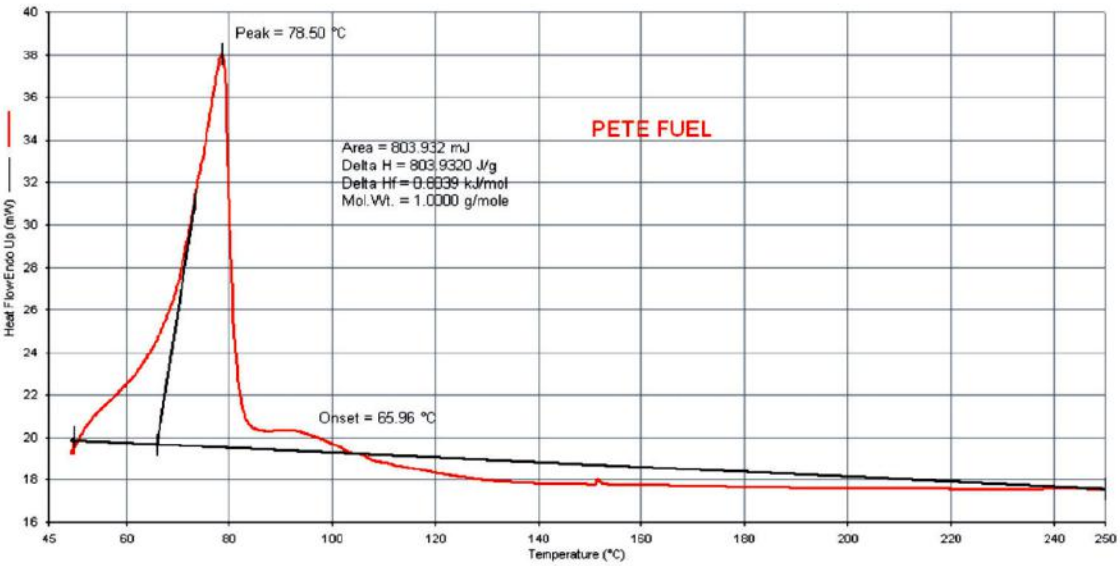

Figure 3: Differential Scanning Calorimeter DSC curve for liquid fuel produced using PET[4]

In addition, several other experiments have been conducted about the thermal degradation of mixtures of PET and LDPE. In one of such experiments, a mixture consisting of 10 grams of PET obtained from disposed water bottles and 50 grams in LDPE obtained from grocery bags had been heated in an atmospheric Pyrex glass reactor of laboratory scale at a temperature range between 250 ^{0}C- 400 ^{0}C[11]. According to the results of this experiment, the product had consisted of 53.5% liquid, 11.83% of gas and 34.67% of wax, and the product liquid fuel had been a light yellow colored liquid with a density of 0.76 g/ml[11]. When comparing with the results of the previous experiment, it is observed that the fuel yield is much higher in the mixture of PET and LDPE than pure PET[11]. After removing wax by means of filtration, liquid and gas streams had been collected separately. The product fuel had mainly consisted of light hydro carbons, but it had also contained various other organic compounds containing up to 22 Carbon atoms. The compounds which were available in significant quantities in resultant fuel were propane, butane, pentane, hexane, heptane, octane, 2-pentene, benzene, cyclo-pentane, 3-methyl hexane and hydro carbons which contained up to 20 carbon atoms[11]. In addition, the resulting fuel had also contained Oxygen containing organic compounds like alcohols and carboxylic acids, due to the presence of ester group in Poly Ethylene Terephthalate. The GC/MS chromatogram for the resulting fuel mixture is given by figure 4.

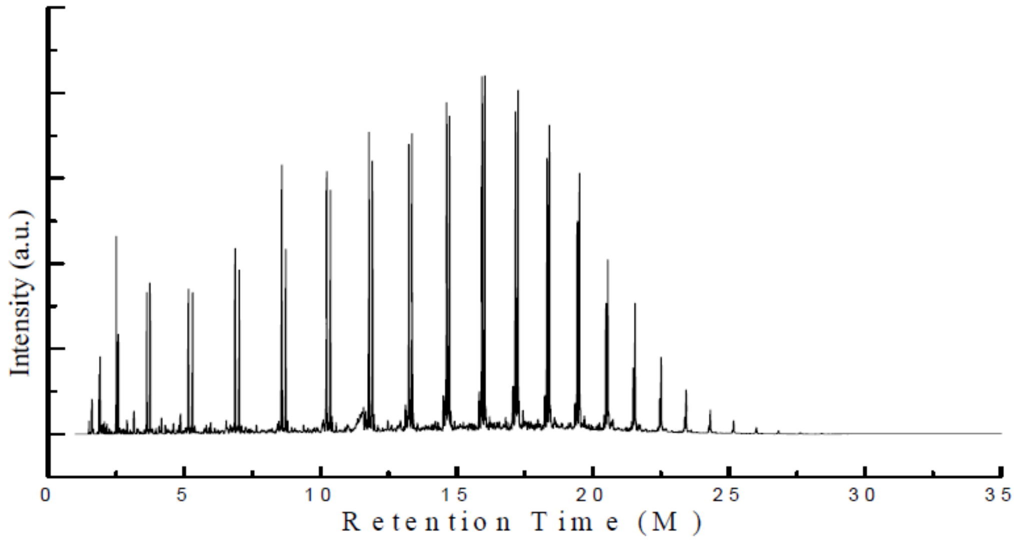

Figure 4: The GC/MS chromatogram of the fuel mixture obtained through thermal degradation of PET and LDPE mixture[11]

Another concept where experiments have been conducted recently based on the useful energy from waste PET is the use of waste plastics as modifiers of the thermo plasticity of coal. Two bituminous coals of different ranks, type

W and SF, and six types of plastics, HDPE, LDPE, PET, PP, PS and ABS had been used in that experiment[12]. Each plastic waste had been cryogenically ground to a particle size of less than 10 mm and mixed with bituminous coal with compositions ranging from 2.5% to 10%, and the blended coal had been tested using Gieseler Plastometer Test and Thermo gravimetric Analysis[12]. According to the results of this experiment, the addition of PET to coal greatly reduced coal fluidity[12]. Since a certain amount of fluidity is required in coal to be used in the production of coke, it is recommended to use PET for combustion or gasification and also in carbon material manufacturing rather than using as an additive in coal because during combustion, power plant authorities prefer a reduction or destruction of caking ability of coal. However, PET can be used as an additive to coal, if it is added in very small quantities[12].

Gasification also has been considered as a method of producing fuel from waste PET. Gasification is considered as an effective sustainable waste management technique, because it can contribute to reduce environmental hazards and land filling as well as maximize energy recovery. A simulation of the gasification process of blends of PET and Polyethylene (PE) had been done using Aspen Plus process simulation software[13]. The resulting gas had been analyzed by measuring product gas composition, gas temperature, lower heating value, gas yield and conversion with respect to CO and H2[13]. According to the results of the simulation, higher PET percentages have given higher Carbon conversion efficiency, due to high Oxygen content in PET. However, Hydrogen conversion has not changed with the increment of PET percentage in the mixture[13]. Therefore, Hydrogen to Carbon Monoxide ratio in product synthesis gas had been lower for PET and PE mixture. Further simulation results revealed that the Hydrogen to Carbon Monoxide ratio was slightly higher in PET and PE mixture than that for pure PET[13]. Therefore, gasification of PET is recommended only in occasions where a low Hydrogen to Carbon Monoxide ratio is required, like large scale methanol production. However, since this is only a simulation, more experiments will be required to be conducted in order to validate this phenomena.

Pyrolysis is another method which can be used to convert plastics into liquid hydro carbons. However, in order to obtain a high yield of fuel, it is recommended to use low density plastics consisting of only Carbon and Hydrogen. PET has a comparatively high density due to the presence of Oxygen atoms, and pyrolysis of PET will mainly give a mixture of Carbon Dioxide and Carbon Monoxide due to the higher content of Oxygen present, with a significant amount of char[14]. Therefore pyrolysis is not considered as an effective method to convert PET into liquid fuel[14].

Conclusion

This research review study was carried out with the objective of investigating a more sustainable solution for the emerging energy and environmental issues related to waste PET. During this study based on existing literature, it was revealed that, waste PET can be converted to corrosion inhibitors and coating applications in metals. As well, it was identified that, waste PET degradation in soil can be accelerated in the presence of specified microorganisms which would be a supportive fact for land filling. Furthermore, it was investigated that, there is a possibility of utilizing waste PET as an admixture in both concrete and asphalt for construction purposes and as a road pavement material respectively. However, conversion of waste PET into useful fuel or energy was identified as a more sustainable solution among all the available alternative approaches. Three main techniques of converting waste PET into liquid hydrocarbon fuels were found out during this study. Those techniques are Catalytic thermal conversion, gasification and pyrolysis respectively. According to existing studies, it was obvious that pyrolysis is not an effective method for conversion of waste PET into liquid fuels. Meanwhile, in both catalytic thermal conversion and gasification, the conversion of PET into fuel is acquired through simple heating of the PET polymer. Therefore, these technologies can be easily implemented using simple machinery with a lower capital cost. However, all of these existing studies are under lab scale research and it has not been determined whether the same efficiency of the lab scale plants can be achieved in industrial scale. The common problem available in both these techniques is yield of fuel is low due to the large amounts of solid residue produced as a result of the high Oxygen content in Poly Ethylene Terephthalate. It has not been investigated whether this solid residue can be utilized to produce another useful product or mixed with existing fuel. Therefore, the potential research areas were exposed out of this study for scaling up these technologies to industrial scale and finding suitable alternatives to improve the conversion efficiencies. Therefore, this piece of work can be extended to conduct future studies based on these research problems.

Acknowledgement

The authors would like to acknowledge the Sustainable Energy Authority, Sri Lanka for organizing an annual Energy Symposium by expanding the opportunities to perform and convey the knowledge based on research activities among different disciplinary scholars in Sri Lanka. The authors of this research paper also would like to be grateful to all the researchers whose valuable work were involved in the literature references cited in this research paper. Moreover, the Department of Chemical and Process Engineering, University of Moratuwa must be commemorated for providing resources in this research study.

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Dynamic modeling and simulation of large scale anaerobic digestion plant to treat Municipal Solid Waste generated in Colombo and suburbs

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Abstract

This study investigates the feasibility of applying large scale anaerobic digestion to treat organic fraction of municipal solid waste generated in Colombo and sub urban cities. According to the feasibility study already conducted, 450 MT/d of unsorted MSW is collected to open dumping site. Following source separation, 300 MT/d is available for anaerobic treatment. Total volume of slurry available is 1110 m^3/d and it is proposed to utilize six reactors with daily flow rate of 185 m^3/d. The feed is introduced semi-continuously every day for 7 hr time span. Anaerobic digestion model No.1 (ADM1) is applied for modeling and simulation and was implemented in AQUASIM 2.1f. The AD plant was simulated for 30 days. It was found that biogas production rate and gas composition vary according the feeding pattern and reactor head space contains average compositions of CH4 and CO2of 55% and 30% (v/v) respectively. Average biogas production rate is about 17050 m3/d. Thus the total biogas production from 6 large anaerobic reactors is 10.23x104 m^3/d. Bulk liquid pH varies around 7 to 7.2 which confirms the stability of the biogas reactor. Biogas generated can be used to produce electricity or filled in gas cylinders for subsequent utilization.

Key words: ADM1; Anaerobic-digestion; MSW; Dynamic Modeling

Introduction

Municipalities and urban councils in Sri lanka collect Municipal Solid Wastes (MSW) generated in households, markets, institutions etc. Most of these MSW are openly dumped to identified lands leading to severe environmental and health hazards. The current generation of MSW in the Western Province is 3,200-3,500 metric tons per day and only 65-70% of these generated waste are collected. The per capita generation varies between 1.0-0.4 kg/d. The waste generation rate increases by 1.2-2% per annum with a predicted 5,800 MT/d in the year 2050 [1]. One of the open dumping site called Karadiyana situated within western province receives 450 MT/d of unsorted MSW from surrounding urban councils and municipalities. Objectives of this study are to introduce large scale anaerobic digestion as a sustainable technology for treating biodegradable organic fraction of MSW and generate electricity and fertilizer. Feasibility of establishing such large scale plant is investigated via dynamic modeling and simulation. Anaerobic digestion model No.1 (ADM1) developed by International Water Association [2] is built in a simulator called Aquasim 2.1f and simulation is performed to study dynamic behavior of the process.

Materials and methods

Schematic diagram of the simplified process is shown in Fig.1. Unsorted MSW received into site is pretreated for removal of plastics, polythene, metals and other materials and only organic fraction of MSW are separated. By adding water,slurry of MSW is prepared into buffer tank. Then this slurry is semi continuously fed to completely mixed high rate anaerobic digesters where anaerobic digestion takes place. Biogas generated is upgraded using scrubbing and subsequently used for electricity generation and production of heat. Digested slurry is transferred into sedimentation tank where sludge and water are separated. Water is recycled back to the pretreatment section as dilution water. Water contains in the sludge is removed via either decantation or centrifuge and following aerobic composting, digestate is used as fertilizer.

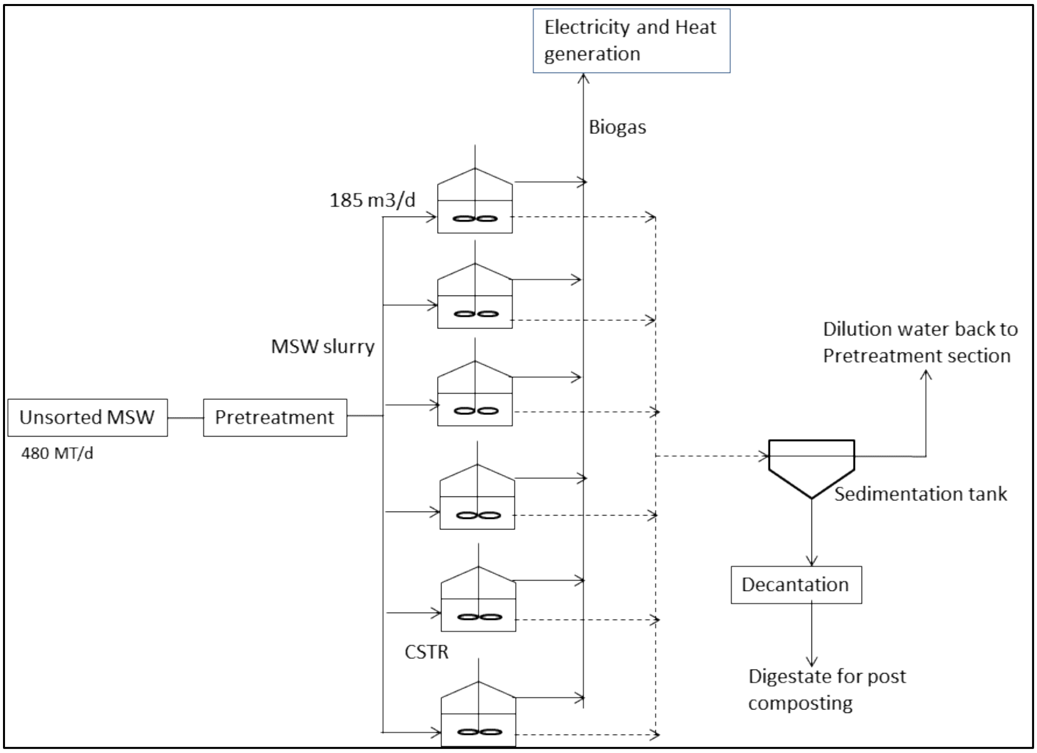

Figure 1: Schematic diagram of simplified large scale anaerobic digestion plant

Collection of MSW

The daily average amount of unsorted MSW receiving toKaradiyana open dumping site fromMoratuwa UC, Kesbewa UC, Boralesgamuwa UC, Dehiwala-Mt. Lavinia MC, Srijayawardanapura Kotte MC, Maharagama UC, and Homagama UC is given in Fig.2

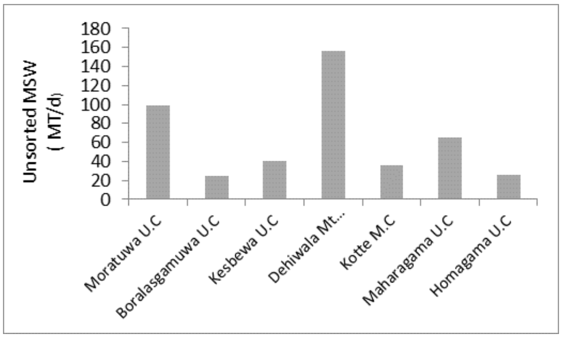

Figure 2: Current collection of MSW into Karadiyana open dumping site from surrounding municipal councils and urban councils (Adapted from feasibility report from Rathnasiri and Abeywarna 2014)

Pretreatment and characterization of MSW

Proposed plant consists of six large scale completely mixed reactors each having volume of 3700 m^3 and hydraulic retention time of 20 days (HRT). Parameters related to conversion of unsorted MSW into slurry are shown in Table 1.

Table 1: Characterization of MSW

Total amount of unsorted MSW	450 MT/d
Total amount of source separated MSW	300 MT/d
Moisture content of MSW	63%
Total solid content in MSW slurry	10%
Flow rate of slurry	1110 m^3/d
Hydraulic retention time (HRT)	20 d
Flow rate per reactor (there are 6 CSTR in parallel)	185 m^3/d
Bulk liquid volume of each reactor	3700 m^3
Head space of reactor	370 m^3

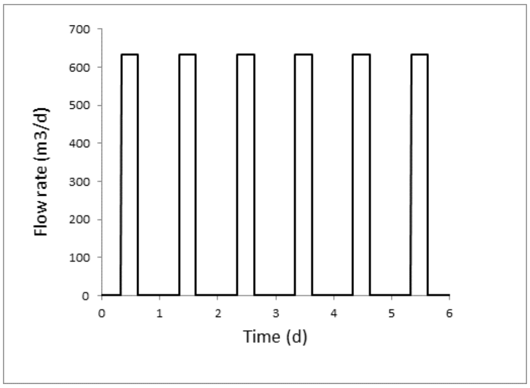

Figure 3: Input flow pattern (semi continuous feeding) to reactor

As dictated by ADM1, reactor input must be characterized into its constituents in terms of Carbohydrates, Proteins and Lipids. Measured TVS (55.6 kg/m^3) of MSW slurry [3]was used to calculate the loading rates TVS in kg/d. Scenario 1 is defined by splitting its constituents into equal ratios (0.33% fat, 0.33% protein, and 0.33% carbohydrates) and COD loads for each constituent wasthen calculated. OLR s calculated is given in Fig.4. To evaluate the effect of varying input values of each constituent, sensitivity analysis was performed and discussed under results section.

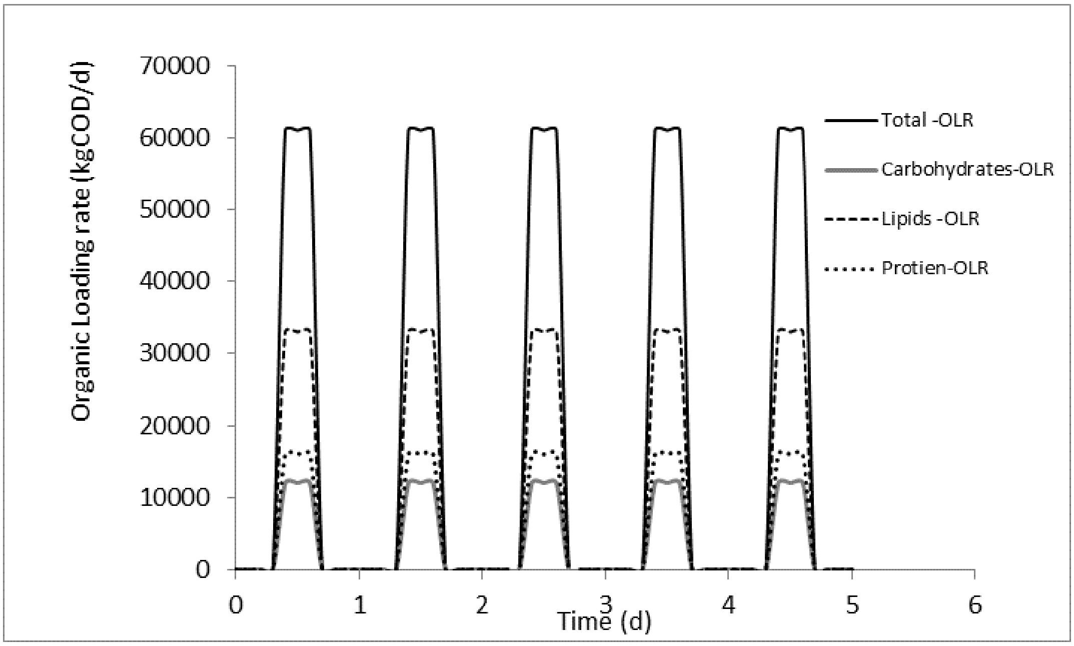

Figure 4: Input organic loading rates (OLR) to ADM1 model.

Simulation and sensitivity analysis

Standard kinetic parameters used in original ADM1[2] were used in this simulation. Input parameters and reactor configuration were set as required by Aquasim 2.1f [4]. For simulation, time step size was 0.1 d and number of steps was 300 to get total time span of 30 days. Three tasks can be accomplished using Aquasim simulator ie simulation, sensitivity analysis and parameter estimation. Sensitivity analysis is conducted using absolute relative sensitivity function given in Eq. 01.

$$\delta_{y,p}^{a,r} = p\frac{\partial y}{\partial p} \qquad \text{Eq.01}$$

By varying value of parameter p, variable y is evaluated. In this study, p is input waste concentration and y is head space CO2 composition. Further input composition of organic material directly affects the biogas composition which is the critical factor for operation of generator. Relative effects of proteins, carbohydrates and lipids in the feed are studied using the results obtained from sensitivity analysis (Fig.5).

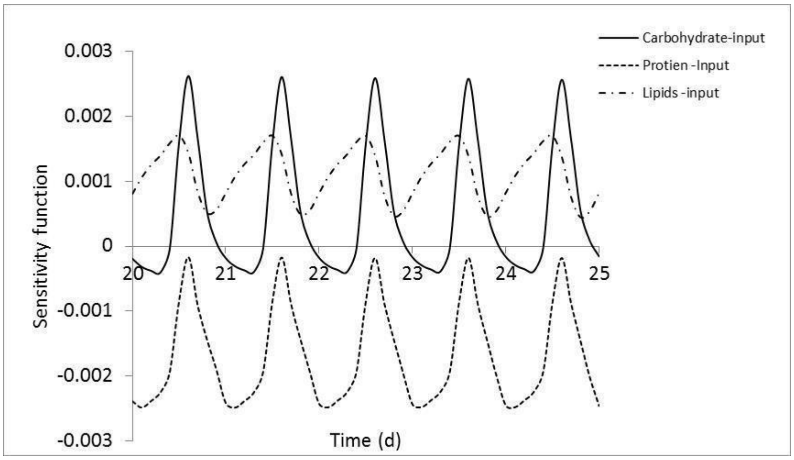

Figure 5: Sensitivity of input constituents towards CO_2 composition of biogas

According to the results from sensitivity analysis, it can be concluded that the input carbohydrate concentration has the highest sensitivity towards CO_2 composition in biogas. This is due to the fast hydrolysis of particulate carbohydrates. But input waste considered in this study has the highest OLR for lipids, next proteins and the lowest for carbohydrates.

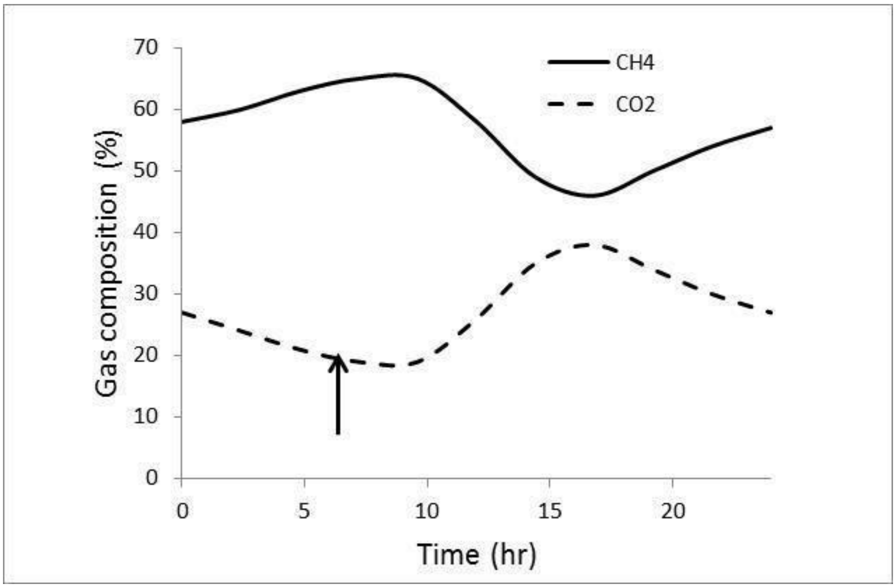

Figure 6: Simulated biogas composition variation following daily feeding.

This is reflected in simulated biogas composition shown in Fig.6. Following feeding, CO_2 composition increases and CH_4 composition decreases for the period of 8 hrs. Initial conversion step of anaerobic digestion is the acedogenes is (fermentation) which is fast compared in rest of the conversion steps. During initial time span, more CO_2 is produced and also more biogas is produced (Fig.7). Average composition of CH_4 and CO_2 is 55% and 30 % respectively.

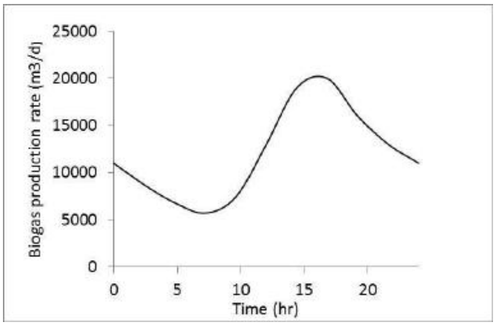

Figure 7: Biogas production rate following feeding

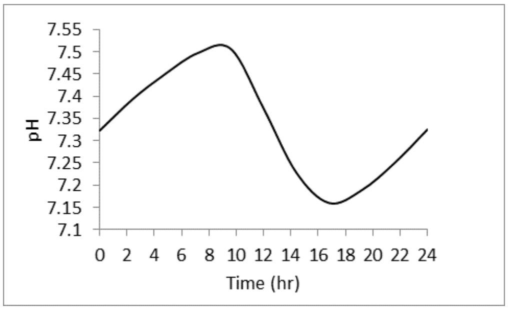

Figure 8: pH variation inside bulk liquid after

Stability of an anaerobic digester [5] mainly depends on the operating pH value. In the ADM1 model, pH is determined using cation and anion balance in the liquid phase. According to the Figure 8 average pH is around 7.3 and ideal for the growth of methenogens. Under the stable operation, reactor acetic acid concentration lies between 300 – 5000 mg/l. According to Fig.9, average acetic acid concentration is 2800 mg/l and presence of fatty acid is due to the high organic loading of lipids. Volatile fatty acids such as butyric, propionic and valearate presence in minor concentrations and not shown in Fig.9

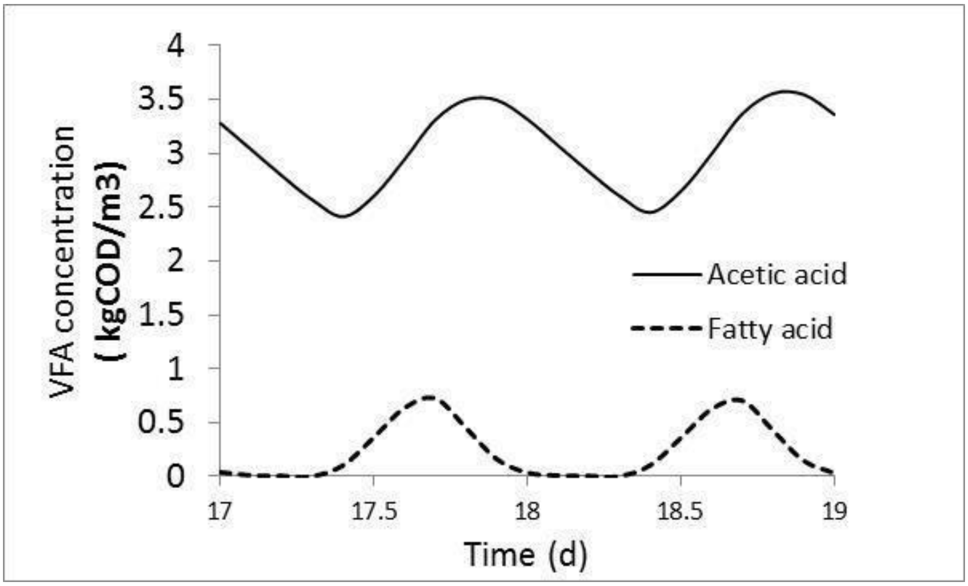

Figure 9: Volatile fatty acids variation in the liquid phase.

Conclusions

Large scale high rate anaerobic digestion plant treating MSW is dynamically simulated using ADM1. Since the plant is fed semi continuously, output parameters show transient behavior. Before designing an anaerobic process, sensitivity analysis can be performed to screen the different input waste compositions. The average gas composition in head space, reactor pH value and volatile fatty acids obtained from simulation show the stable anaerobic reactor operation. These simulation results further confirm that standard kinetic parameters used in ADM1 are capable of simulating large scale anaerobic plant. To increase the accuracy of the ADM1 model, experimental specific kinetic parameters relevant to particular waste must be used. The biogas production from six large scale reactors can be used for power generation.

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Biogas Production Using Fruit Wastes

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Abstract

The study conducted in a reputed fruits production company in Sri Lanka namely of Country Style Foods Ltd with a brand name of SMAK. The main fruit waste of Country Style Foods Ltd. (pineapple peel, mango peel, papaya peel, rotten woodapple and pulp) were tested anaerobically for biogas production in batch fed barreled digesters (6 nos.) each having capacity of 45 l. The chopped materials (about 30cm) having a weight of 25 kg were mixed with 2.5 kg of cow dung before feeding to each digester. The daily parameters measured were rate of gas production, pH and temperature.

Biogas production commenced within 2 hours period. The highest average yield was recorded from the pulp system (average yield of 12.29 l/kg) due to the smallest particle size (dia.< 100µm) and the higher percentage of biodegradable material. Mixed peel obtained average yield of 6.42 l/kg and its C:N ratio also favored for the digestion (27.93).

The effective gas from which, observed clear blue flame after one week of the feeding, was very much lower than that of total gas production in each systems. Released effective gas contents were 3.53 l/kg, 1.65 l/kg 0.76 l/kg, 0.32 l/kg, 0.26 l/kg and 0.056 l/kg from the pulp, mixed peel, papaya peel, pineapple peel, mango peel and rotten woodapple respectively. Hence selected mixed peel composition was highly suitable for the biogas production. But in order to transform unavailable (organic nitrogen) nitrogen of fruit residues to biodegradable nitrogen, it is essential to first compost them for about one week before feeding into digester, which will result automatically adjusting of pH level in the digester. This will reduce the higher initial investment and maintenance cost for the requirement of standard high rate digester systems or two stage digester systems.

Introduction

Country Style Foods Ltd. produces the best quality natural fruit drink having a brand name of "SMAK". The average production rate is about 80,000 bottles per day each having a capacity of 190ml of fruit drink. Hence daily drink production rate is about 15,200 liters.
According to past data collection, it has been found that the peels which account for 32%, 22%, 15% and 10% of the total weight of pineapple, mango, papaya and woodapple respectively, become waste. Usually 2.4% of pulp (waste) produces from total weight of total used fruits. The recorded values within year 2001-2003 reveal that average total fruits waste production rate range in 1600- 1800 kg per day. Fruit waste contains high volatile solids range in 80-90% and moisture content of 75-85%. Because of higher biodegradable nature these fruit wastes, after giving anaerobic conditions, Biogas and compost can be obtained, which can subsequently be used to dehydrate fresh fruits and enrich the soils as organic fertilizers.
The main objective of this preliminary stage experiment was to perform a test experiment usingseparately all available fruit residues and one experiment with multiple sources.

Experimental setup

Fig.1 shows the schematic diagram for the experimental set up used for the study. The unit consists of three barrels of which the outer barrel was used to seal the gas, middle barrel for gas collection and the inner barrel as the digester. 6 nos. of such units were designed for separatefruit waste each having a capacity of 45 l. Since the density and the total solids of substrate were very low, scum formation occurs during anaerobic digestion. Therefore, to overcome this operational problem, especially when collecting the sludge for analysis, a stirrer was fixed to the gas holder of the unit.

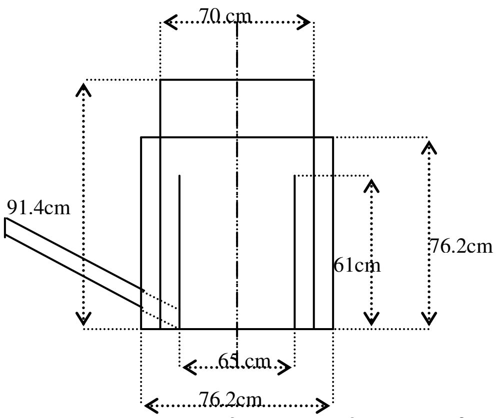

Figure 01: Schematic diagram for preliminary stage digester

Material and Method

This experiment was carried out in an open area located at the Country Style Foods Ltd, Kadawatha, Sri Lanka using 6 nos. of pilot scale batch fed barreled digesters (Fig 2a) mentioned earlier. The experiment was started on 24th October2006. The main substrate used were pineapple peel, mango peel, papaya peel, woodapple, pulp (Table 01) and one with having a combination as shown in (Table 02). Pulp is the thickened sludge which filtered from boiled mixed fruit juice.

Table 01: Feed composition

Feed material	Amount (kg)	Cow dung Added (kg)	Initial pH	Initial Temperature (^0C)
Pulp	25	2.5	7.2	31
Pineapple	25	2.5	7.1	35
Mango	25	2.5	7.1	36
Papaya	25	2.5	7.1	32
Woodapple	25	2.5	7.1	34
Mixed peel	25	2.5	7.1	33

Table 02: Composition of mixed peel

Material	Amount (kg)
Pineapple	10
Mango	6
Papaya	4
Woodapple	4
Pulp	1

Fresh cow dung for the mixing of the substrate was first inoculated for a period of about 2 days and then cow dung was mixed with water (i.e. to a ratio of 1:1). The substrates were chopped into about 30cm pieces separately. The chopped materials were mixed with cow dung (Fig.2a) thoroughly and fed into each digester (2b) and sealed with water. The digester contents were thoroughly stirred prior to taking measurements of physiochemical parameters at the sludge port. The experiment was done about one and half month under the ambient temperature.

Figure 2a: Batch fed barreled digesters

Figure 2b: Substrate were mixed with cow dung & water

Figure 2c: Substrate fed to the digester

Figure 02: Preliminary stage biogas experiment at Country Style Foods Ltd

Data Collection

The rate of gas production, pH and temperature were measured daily. Biogas production was measured using the technique described by [5] (water displacement method).

Analysis

Analysis was done in the initial stage of the experiment.

- Total Solids (TS)
- Total Volatile Solids (VS)
- Total Organic Carbon (TOC)
- Total Nitrogen (TN)
- Total Phosphorous (TP)

Results & Discussion

The key factors that influence the biogas production in anaerobic digestion are C:N ratio, volatile solids, pH, temperature, particle size, dilution, consistency of inputs, loading rate, and retention time. If these key factors are within their normal range it would experience an effective gas production.

C:N and C:P ratios of the substrates

The composition of the organic matter and proper amount of nitrogen in a digestion system has an important role on the growth rate of anaerobic bacteria and production of biogas. FAO/CMS (1996), manifested that C:N ratio within the range of 20-30 is the optimum ratio for anaerobic digestion. However our results show that only woodapple (26.38) and mixed peel (27.93) lie within that range. C:N ratio of pulp (123.34), mango peel (69.31) and pineapple peel (63.71) were very much higher than the above range, while papaya peel was less (15.81).

Nitrogen present in the feeds stock provides an essential element for synthesis of amino acids, proteins and nucleic acids. It converts these acids to ammonia which, as strong base, neutralize the volatile fatty acids produced by fermentative bacteria, and thus helps to maintain neutral pH conditions essential for cell growth [6]. But pH of all the digesters had to adjust during the digestion process since the pH were below 5.5. This reveals that NH_4^+ not achieved due to digestion of nitrogen. Even though papaya peel, rotten woodapple and mixed peel contained proper amount of C:N ratio, NH_4^+ had not being formed due to the fact that not all of the nitrogen in the feedstock were available to be used for digestion (Marchaim, 1992). Further Marchaim (1992), explained that the actual available C:N ratio is a function of feedstock characteristics and digestion operational parameters, and overall C:N values can actually be varied considerably from less than 10 or over 90, and still result in efficient digestion. The results (biogas production) what we got were similar toMarchaim’s findings.

Table03: Nutrient content of the initial substrate

Substrate	Total Organic carbon (%)	Total Nitrogen (%)	Total Phosphorous (%)	C/N ratio	C/P ratio
Pulp	55.59	0.44	0.005	126.34	11118.00
Pineapple peel	52.25	0.82	0.070	63.71	746.40
Mango peel	61.00	0.88	0.045	69.31	1355.5
papaya peel	45.76	2.89	0.182	15.81	251.43
Rotten woodapple	40.10	1.52	0.089	26.38	450.56
Mixed peel	49.17	1.76	0.096	27.93	512.18

FAO/CMS (1996) stated that C:P ratio around 166 is the optimum value. However our results show that C:P ratio for all the digesters were greater than 251 indicating less amount of phosphorous content than the optimum value.

Table 04: Physiochemical information of initial substrate

Substrate	Total solids (%)	Volatile solids (%)
Pulp	20.21	88.24
Pineapple peel	12.68	92.86
Mango peel	19.51	90.57
Papaya peel	16.96	84.00
Rotten woodapple	49.33	92.97
Mixed peel	18.30	79.72

Table 04 shows that the volatile solids of all the substrate were higher than 79 indicating a good biodegradability of substrates.

Biogas Production

Figure 03 shows the daily biogas production rate with time. Gas production was started within two hours after feeding and sealing of the digesterwhereas usually taken about 1-2 days for observing the gas formation. A gas production of 45.80 l, 43.72 l, 40.56 l, 24.29 l, 23.77 l and 5.20 l were recorded from the pulp,mixed peel, papaya peel, mango peel, pineapple peel and woodapple digesters respectively within one day after charging the reactors (Fig. 3).

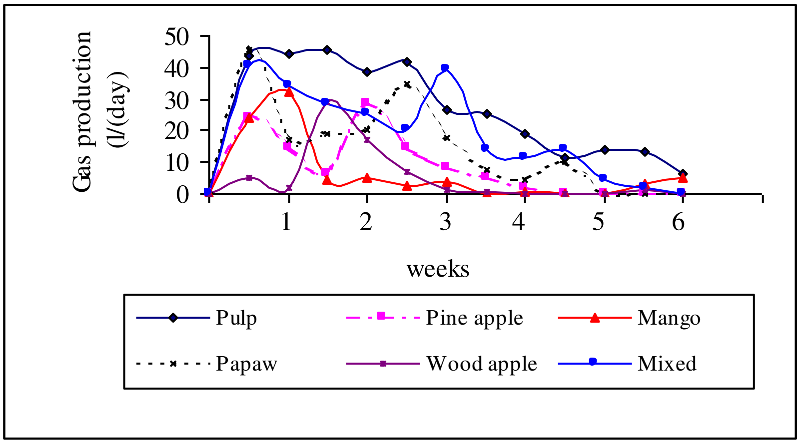

Figure 03: Daily biogas production rate with time

This gas production was mainly in the form of CO_2 since mixing with cow dung effectively and readily exposed the organic substrates to a high population of mixed syntrophic microbes. Thus hydrolysis and acidogenesis occurred rapidly, as the time taken for bacterial acclimatization to the substrates was comparatively short. During this period the growth of acidogens were high and the initial pH of the substrates (7.1-7.2) favored the fermentation of carbohydrates and proteins by acidogenesis as the optimum pH for acidogenesis of carbohydrates and proteins is 5.8 and 7.2, respectively [1].

The highest gas production rate was observed in the pulp system following mixed digesters amounting to 338 l and 233.82 l during 6 weeks. The total biogas production observed in the papaya, pineapple, mango and woodapple were 176.6 l, 103.21 l, 80.84 l and 63.31 l respectively. The reason for having higher gas production in the pulp system, even though C:N ratio greater than 100 (C/N –123) may be the specific characteristic of material and it's fine particle size reduction (Dia. < 1mm) as discussed in section 6.1. Mixed peel also has obtained a fairly good gas production rate.

However biogas production should continually exist throughout 10-14 weeks. But this was not happened in our experiment due to higher C:N ratio in pulp, pineapple and mango. Nitrogen in the form of ammonia, with small quantities of the nitrite and nitrate has been consumed rapidly by methanogens afro meeting their protein requirement and nitrogen in the form of organic nitrogen has not been no longer react on the left over carbon content of the material. This is the fact that we have obtain this much of lower gas contain (mainly methane). On the other hand nitrogen content in papaya or woodapple was not readily available to be used for digestion as discussed in section 6.1.

Average gas production of pulp, mixed, papaw, pineapple, mango and woodapple were 12.29 l/ kg, 8.5 l/kg, 6.42 l/kg, 3.75 l/kg, 2.92 l/kg and 2.3

l/kg respectively. But during about one week period there was no methanogenesis since methanogens have slow growth rates and are obligate anaerobes. The methanogens were in the lag phase during the initial stages since the environmental conditions were not ideal, especially when the pH was less than 6.2 [7]. Therefore certain time was taken to acclimate to the environmental conditions prior to cell division. As a consequence the quality of biogas produced during the initial stages of the study was poor due to lack of CH_4. In other words there was hardly any blue flame produced when the collected gas was ignited. Therefore effective gas from which, observed clear blue flame was very much lower than total gas production. Effective gas produced were 3.53 l/kg, 1.65 l/kg 0.76 l/kg, 0.32 l/kg, 0.26 l/kg and 0.056 l/kg in the pulp, mixed, papaw, pineapple, mango and wood apple respectively. As discussed in section 6.1 there not any much effect from C:N ratio

Normally methane production rate is less since methanogens have slow growth rates with maximal growth rates of 0.005-0.02 g/g and doubling times of 50-200 hours under optimum environmental conditions [1]. Therefore the effective gas from which, observed clear blue flame was lower than total gas production.

Environmental Parameters

The rate of biogas production is affected by pH and temperature. Both pH and temperature are function of detention time in a digester. This study also manifested a strong relationship between biogas production, and pH & temperature.

A pH range of 6.6-7.6 is required for the growth of syntrophic bacteria [7]. pH less than 4.5-5 suppresses bacterial action [3] and methanogens (which requires an optimum pH in the range of 7.2-7.4) are partially inhibited at a pH of 7 and full inhibition occurs when the pH is less than 6.6. However Metcalf and Eddy (1995) stated that complete methanogenic inhibition occurs when the pH is less than 6.2.

Figure 04 shows the variation of pH with time. The pH values of the initial mixtures were in the range of 7.1-7.2 thus approximating the required initial pH range of 6.6-7.6 [7] for the growth of syntrophic bacteria. However, with time the pH of all digesters were drastically reduced. During the first week of the study a decrease in substrate pH to a range of 3.4-5.4 was observed due to the formation of VFAs including long-chained VFAs in all digesters. The sharp decrease in the pH of the digester contents justified that acidogenesis followed by acetogenesis occurred after rapid hydrolysis of the biopolymers. As the digestion processes continued the pH decreases to less than 3.5. Therefore to overcome this operational problem, lime was added to all digesters to adjust pH value to close to a neutral value.

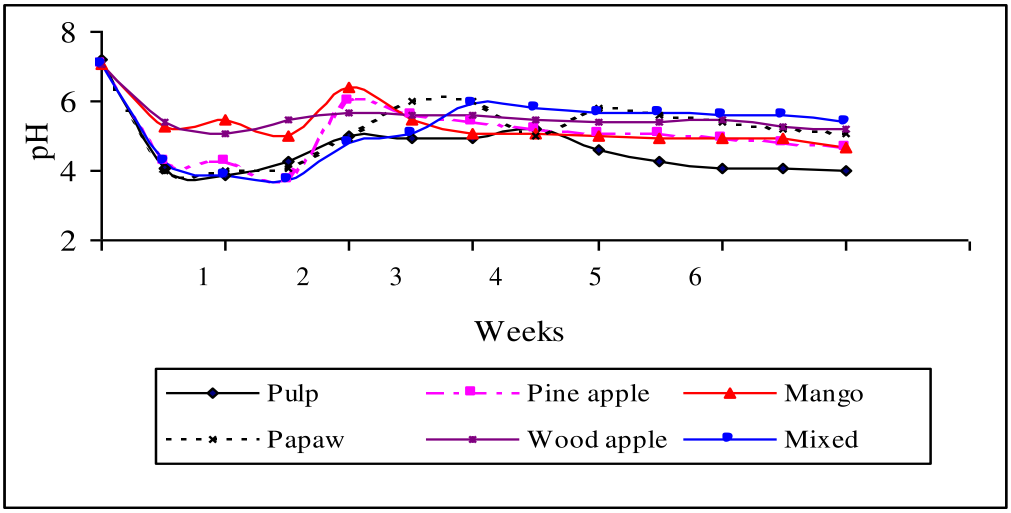

Figure 04: Variation of pH with Time in fruit waste Systems

The results revealed that the pH values of the pulp system was always less than that of other systems throughout the experiment due to the formation of a high concentration organic acids than in other systems. In the pulp system an initial substrate pH of 7.2 undoubtedly favored an optimum growth of acidogens and acetogens.

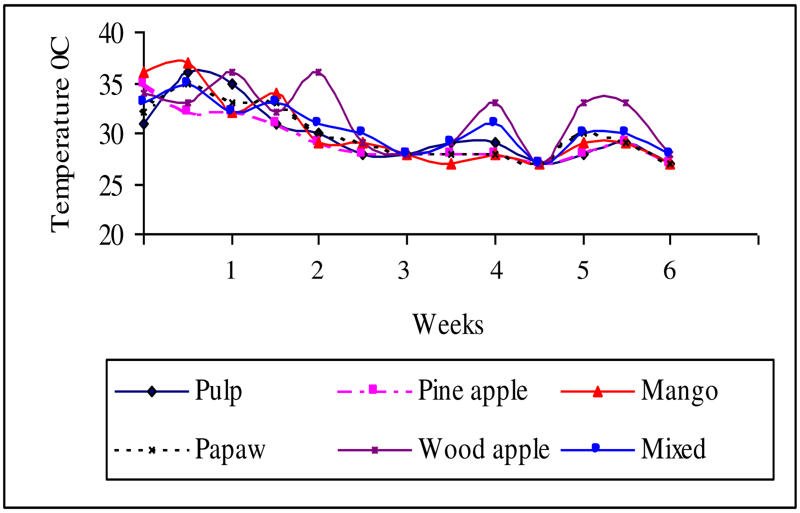

Figure 05: Temperature Variation with Time in fruit waste Systems

The sharp decrease in the substrate pH on comparison with other systems was correlated due to the formation of a high content of VFAs following rapid hydrolysis of the high initial organic C content under optimum pH and favorable temperatures required for bacterial growth.

Figure 05 shows the variation of temperature with time. Initial temperature of all the digesters varied in between 31-36 ^{o}C suggesting that mesophillic bacterial growth (Temperature range of 25-40^{o}C although 35-40^{o}C is the optimum range) [8]. We couldn't observe much difference between ambient temperature and inside of the digesters during the latter part of the experiment due to no heat released as a consequence of biochemical reactions involved in methanogenesis [7].

In these systems mesophillic bacteria played a crucial role in performing the biochemical reactions of the 4 stages involved in the production of biogas. Mesophillic bacterial growth was favored as the digesters used were standard rate digesters with no external or internal heating and thorough substrate mixing mechanisms.

Recommendations

From the results of this experiment it can be recommended that mixed peel composition was well suit for the anaerobic digestion since it had a C:N(27.93) ratio which was within the range of optimum ratios (20-30) and it has produced a good effective biogas production (1.65 l/kg) comparing to other individual systems. But the present study demonstrated that C:N ratio has not shown much effect due to the fact that nitrogen present in the fruit peel was not in the available form for the digestion. Therefore to make these nitrogen into degradable form, the feed material should compost for about one week as a pretreatment.

Further the particle size reduction to 5 –10 cm will enhance the biogas production since it will create more active area for the micro-organisms.

Conclusion

In this study biogas production commenced as CO_2 within 2 hours since the experiment start up despite the fact that the C:N ratios of the substrates did not approach to the optimum range.

The highest average yield was recorded from the pulp system (average yield of 12.29 l/kg) even though C:N ratio as higher than 100 due to the smallest particle size (dia.< 100µm) and it contain higher biodegradable material. Mixed peel also obtained a good yield of average biogas production of 6.42 l/kg and it's C:N ratio was also favored for the digestion (27.93).

As a consequence, the quality of biogas produced during the initial stages of the study was poor due to lack of CH_4. In other words there was hardly any blue flame produced when the collected gas was ignited. Therefore effective gas from which, observed clear blue flame was very much lower than total gas production. Effective gas produced were 3.53 l/kg, 1.65 l/kg 0.76 l/kg, 0.32 l/kg, 0.26 l/kg and 0.056 l/kg in the pulp, mixed, papaya, pineapple, mango and woodapple systems respectively.

The selected mixed peel composition was well suit compared to the individual material except pulp system (comparing gas production). On the other hand daily quantity of fruit peel that can be collected for the mixed peel system was very much higher than pulp material. Further C:N ratio of mixed peel was favorable for effective biogas production. But, in order to transform available nitrogen of fruit residues to biodegradable nitrogen, it is necessary to first compost for about one week which, will result automatically adjusting of pH level in the digester. This will reduce the higher initial investment and maintenance cost for the requirement of standard high rate digester systems or two stages digester systems.

Acknowledgments

The author is grateful to Mr. S.W.Alahakoon/ Chairman, Country Style Foods Ltd. for granting funds and his contribution for this project. NERD Center is specially acknowledged for assisting the digester designing and their contribution for this project. The author is also grateful to University of Colombo, Sri Lanka for performing analytical tests of fruit wastes.

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Small scale appropriate energy technologies in meeting basic energy needs of Sri Lanka – success and failure factors

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Abstract

Appropriate small scale energy technologies were introduced to Sri Lanka to meet basis energy needs of the poor people and those living in off-grid areas. The technologies include micro hydro village electrification schemes, biogas systems, improved biomass cooking stoves, small wind electricity turbines, biodiesel and pico hydro systems. The projects were initiated with philanthropic support and evolved into community based solutions with a considerable contribution by the energy users.Community based energy technologies fail with withdrawal of donor assistance, if they are heavily subsidised and proper stake by the recipients are lacking. They are sustainable if they are transformed into commercial ventures. Awareness creation, facilitating an enabling environment, development of human capital and local technology development has shown sustainability of promoted technologies. These interventions have led to establishment of a small industry as seen from biogas, improved cooking stoves and hydro technologies. Lack of after sales services and withdrawal of donor assistance has led small wind energy technologies and biodiesel interventions to be stranded. Overall cost, convenience, reliability, access to finance, after sales services, quality of energy and external catalyst support have contributed towards success. This paper is aimed at identifying the approach, the process and results of these attempts.

Key words : Appropriate energy technologies, village electrification, micro hydro, biogas, cooking stoves, wind, biodiesel, pico hydro, financing, energy poverty, policies, practices, sustainable

Introduction

The energy ladder demonstrates that as the incomes of the households increase, the types of energy used by them would be cleaner and more efficient. Biomass is a cheaper but less efficient fuel while electricity is an efficient but expensive source of energy. Electricity was first felt in Sri Lanka in 1890 with an electric lamp seen in a German ship while a hotel in Colombo had some electric lamps lit in a ballroom in 1895. The early part of 20th century, in 1902, Sri Lanka had the first power plant, of a capacity of 3MW from steam.

Electricity and liquefied petroleum gas are the main clean energy sources used in Sri Lanka. Only less than 30% of the households were electrified in Sri Lanka by the year 1990 while the electrification rate was quite low. In order to meet the basic energy demands of the populace, both the government and none governmental sectors took initiatives to provide energy to the people, particularly prioritizing energy for cooking and lighting. Intermediate Technology Development Group, now known as Practical Action played a vital role in providing access to cleaner energy sources particularly to the poor people of Sri Lanka adopting a community based approach since 1979.

By the end of 2012, grid electrification was 94% in Sri Lanka, although over 46% of the primary energy in Sri Lanka is biomass in 2012. The success and failure factors of the small scale appropriate energy technologies such as micro hydro village electrification schemes, biogas systems, improved biomass cooking stoves, small wind electricity turbines, biodiesel and pico hydro unitsby Practical Action in meeting basic energy needs of Sri Lanka are described below. Some aspects intervened in relations to policies and practices at various levels in support of the promotion of the technologies are included.

Micro hydro village electrification schemes

Those who first tapped the hydro power in Sri Lanka were the planters. They established hydro power systems for electricity generation and to provide motive power. These have been used in their own plantation industries using the nearby small streams. It is estimated that, by the early 1900s, there had been about 500 of such in Sri Lanka. With the introduction of grid electricity, their prominencehas become insignificant as main grid electricity was more convenient and versatile.

Practical Action initiated its projects on micro hydro in 1991. This began with rehabilitating some abandoned 10 micro hydro systems from the estate sector, which provided a testing ground and evolved into introducing the micro hydro village electrification schemes for off-grid communities to have access to electricity. It has directly or indirectly contributed to about 180 such schemes out of the estimated total of around over 300 such schemes in the country.

These systems were of run-of river type where there is no storage of water, but only a diversion of portion of the stream through the power plant. Diverted water is channeled back to the initial stream. Typical capacities of these are from 5 kW to 50 kW, and most are with a higher head and used Pelton type turbines. The turbines are locally manufactured while the power generators were often the electric motors bought from the open market and converted locally into a power generator. The 230V 50Hz electricity is then distributed through a mini-grid to the households. Each house was limited to have around 100 – 200 W at a time.

During the early stage, the approach was for the technical experts to implement the project with little involvement of community. Financing came entirely from donors and philanthropies. With time, the involvement, participation and stake of the community increased while the capacities of the key stakeholders were further strengthened. Awareness programmes were conducted targeting the village leaders, students and decision makers in particular while national and international level training was provided to engineers in designing, developers, technicians, manufacturers and equipment suppliers etc. Following the 'village development societies' model 'electricity consumer societies' were formed where these were involved in arranging the labour or sweat equity; fund raising and linking with financial institutions;attending to the operations and maintenance; designing, collection and managing the tariff, providing security and control of electricity consumption.

Awareness and training led to develop the village hydroelectricity schemes to an industry. Private sector developers with manufacturers who were trained could develop projects and source financing from established institutions. Government introduced a system to purchase electricity from the small power producers around 1997 and the instrument standardized power purchase agreement for power plants of capacity less than 10 MW offered a scheme for calculating purchase price encouraged developers to connect electricity to the national electricity grid with small hydro plants, a developed version of micro hydro schemes. Energy Service Delivery and Renewable Energy for Rural Economic Development projects played a pivotal role in expanding this industry further. In the year 2001, nearly 1,050 sites were identified from 10 districts of Sri Lanka to have a potential for micro hydro schemes. The autonomous electricity consumer societies were integrated into a federation while national code of practice was endorsed for micro hydro schemes. Southern, Uva, Sabaragamuwa and Central provincial councils accepted hydro energy from village electrification schemes to be a viable option for providing electricity and made budgetary provisions with projects in place in their annual calendars. Southern provincial council incorporated a stature related to alternative energy, which can encompass village electrification schemes, while others made similar efforts.

Assessment of the potential, development of the local human resources, introduction of the financial schemes, catalyst support provided by development agencies, technical guidelines and standards, political and administrative leadership accepting and promoting these, having a considerable technical potential in the villages for hydro power and the lower probabilities of the main electricity grid reaching their villages in the foreseeable futures, loans being available from the main financial institutions, mainly from commercial banks and trends in deviating towards greener and sustainable sources of energy etc contributed as success factors for development of micro hydro village electrification schemes in Sri Lanka. However, cost of electricity being fairy expensive against the cost of grid electricity, lower power quality and frequent break-downs, some difficulties in operations and maintenance, supply of electricity to be limited in the range of less than 200W per household which prevents households from using electricity for industrial, commercial and some commonly used appliances elsewhere, main electricity grid reaching the village at a later time etc are seen as challenges.

Biogas systems

Biogas systems were first introduced to Sri Lanka by the University of Peradeniya in early 1970s. Since then, about 7,000 biogas systems have been installed in the country of various designs and sizes. These have been first installed in government institutions, but very soon have got abandoned due to many reasons, including lack of operations and maintenance, lack of interest by the proceeding officials who were responsible for the institution or the biogas system and technical errors. After some evaluations and revamp, some of these were rehabilitated and new biogas systems were introduced for domestic use.

Similar to the micro hydro village electrification schemes, donor funding met the full cost of putting up early biogas systems and their rehabilitation while local human resources were developed with a similar approach. The latter stages required the households to make a contribution at-least in terms of sweat equity and providing locally available material while development agencies or the government provided the major cost component. From the recent past, the none-commercial agencies promoting biogas systems mandated the households to make a financial contribution too while micro financing systems and agencies were linked to part finance biogas systems. Bank loans had been provided from leading state commercial banks in 1980s.

Early biogas systems were built manly to provide energy for lighting and cooking, but now they are advocated in a triple benefit nexus positioning biogas within sustainable energy, none chemical inputs agriculture and waste management from an environmental perspective. From a technical angle, continuous feeding floating drum was the biogas systems introduced in the early stages while the continuous feeding fixed dome had been introduced from latter part of 1970s.

These are the most prominent and well proven biogas types commissioned in the country. Dry batch fixed dome biogas systems with a floating drum gas storage facility also had been introduced, particularly suitable for wastes or agricultural residues of dry organic matterwith little success.

In the recent past, smaller biogas systems for domestic use, particularly in the urban sector, has been introduced which are portable units and available in the market to purchase off the shelf. Plug flow biogas systems have also been recently introduced which are suitable to help manage the floating organic waste such as organic components of market garbage, weeds, food waste etc. Most of the domestic biogas systems are in the range of 6-12 m^3 digester capacity while biogas systems upto about $200m^3$ are found. Common purpose of introducing biogas in early stages was for lighting and cooking. The popular application these days is limited to cooking purpose as a substitute for liquefied petroleum gas. There have been occasional applications of power generation, water pumping and running vehicles using biogas.

Increase of biogas developers led to the formation of a biogas developers' collective, which was an informal arrangement among the developers who had some common practices such as building biogas systems according to some guidelines, training of masons, training younger generation as technical officers, keeping a field record of these trainees, issue of a warranty certificate for the constructed biogas systems with an agreed follow-up schedule, providing training on integrated farming practices associated with the biogas systems and providing the users with an operations and maintenance manual, providing a general awareness and training on operations and maintenance to the users, giving a reference serial number to the biogas systems constructed etc. Along with these, the Technical Advisory Committee on development of national standards on domestic biogas systems shared intellectual knowledge and experiences among the experts while this committee evolved and expanded to become the Lanka Biogas Association as a national body promoting biogas in Sri Lanka. This, along with Practical Action and Sri Lanka Sustainable Energy Authority initiated establishment of a National Biogas Programme with the leadership of the Authority, which is yet to see the bright daylight.

Integrated biogas systems with farming, dairy and livestock; well distributed network of biogas developers and masons who can construct biogas systems; ability to provide triple benefits of sustainable energy, agricultural inputs and waste management; continued biogas propagating programmes by the state institutions with part financial support; availability of guidelines, national standards, norms, established practices and manuals; environmental regulations leading towards establishment of biogas systems as one of the solutions in waste management; biogas systems adding values to dairy so that sustenance of small scale dairy sector; providing increased livelihoods options and lower pay-back period are some factors leading towards success of biogas systems. However, requirements for continuous feeding of raw material; continued operations and maintenance; higher initial cost; lack of appliances with competitive suppliers and pricing; weak after sales support; lack of a proper warranty and guarantee system and weaknesses in adapting technologies to provide tailor made solutions etc some of the limiting factors. Although technicians and masons are in a position to design and construct biogas systems, a clear gap in research and development, transfer of technologies or incorporating structural and process engineering aspects are found so that the technical advancements take place very slow.

Improved biomass cooking stoves

Nearly half of primary energy in Sri Lanka is contributed by biomass. Most of this is used in the domestic sector and it is for household cooking. Using biomassin inefficient cooking stoves leads to many repercussions including indoor air pollution. This polluted air can contain a variety of health damaging pollutants leading to acute and chronic respiratory conditions such as pneumonia, lung cancer, cataract, stroke and ischemic heart disease. There said to be supporting evidence suggesting that exposure to household air pollution is linked with adverse pregnancy outcomes, tuberculosis, upper aero-digestive tract, cervical and other cancers. Recognizing these and other factors such as deforestation; land degradation; drudgery in fuel wood collection, storage and use etc, many initiatives have taken place to introduce energy efficient cooking stoves that emit low smoke and associated pollutants, uses less fuelwood leading to cooking within a shorter time with less hassle.

Improved Cooking Stoves have been introduced to Sri Lanka in the 1950s with the stove called Herl Chula. However, the interest and momentum gained in early 1970s. A national NGO initiated a stove programme from 1979 – 1983 while Practical Action had its Urban Stoves Programme from 1987-1989. In order to sustain the cook stoves programme further, it also contributed towards establishing Integrated Development Association, which since then has played a significant role in commercializing biomass cook stoves. Today, it is estimated that nearly 400,000 improved clay cooking stoves are produced in the country by the small scale potters.

Some of the important lessons learnt from improved cooking stoves programmes include that entire cookstoves dissemination process has to be put in shape that includes design, production, promotion and marketing and it is not only the improvement of technical designs; both users and producers have to be taken into account; subsidies can hinder the sustainability; it is not essential for the formal sector to participate as an ingredient in commercialization; sharing experiences and lessons; providing institutional support on Research & Development, training, promotion etc; need for introducing stoves not necessarily as an energy intervention but more appropriately as an intervention with an integrated development process at domestic or community levels related to health, saving time and drudgery, energy shortages, income generation and social factors of both users and producers.

Recognizing the importance of assessment of biogas for energy in the country, Practical Action developed a methodology and pilot tested same with assessment of biomass resources from the household, farm and individual plantation levels through the government administrative mechanism; physically studying the biomass movements by quantifying biomass imports into and exports out of a geographical area and assessing the production and consumption from within the same area and plotting them using a participatory market systems mapping and participatory market system development approach which quantified the movements of biomass also recognizing the policy influencers, market players, key stake holders and infrastructure; assessing the green cover using GIS technologies out of which well-established conversion factors could estimate the biomass availability for energy purposes.

Some key important features of cookstoves programme were paying attention to both users and producers at the same time, the product being sold extremely low cost with a payback period of about 3 months, production being done in clusters of villages similar to industrial clusters, comprehensive training provided, standards and quality being considered from the beginning of the interventions, fairly a good income to producers so that even the younger generation continuing with production, use of already established distribution channels with a substantial profit margin, reaching the far ends of the villages while product being available in the shops in the towns and townships etc. However, there are restrictions in mining and transportation of clay, the fast depletion of suitable clay, lack of research and development in further improvements done (still a considerable amount of smoke is released although smoke released from chimney connected stoves are lesser), inability of the stoves to accommodate different sizes of pots with a wide range, life of a stove being upto about 2 years are some of the challenges needs to overcome.

Establishment of national standards for the most common improved biomass stove can be considered as an important step where Sri Lanka has become one of the first if not the first country to develop such standards.

Small wind electricity turbines

Being an island and developed nation in the past, Sri Lanka has shown that she has used wind energy in metal industry in blacksmiths producing Damascus swords and exporting to Western Asia, sailing in the ocean and milling grains including rice. Use of wind turbines has got attention in the 1970s where Water Resource Board and other agencies have promoted wind mills for water pumping for agriculture purposes in the northern area of the Sri Lanka. Using wind for power generation for communities and domestic purposes has taken place from during the latter part of 1990s. There had been some attempts to assess the wind potential for power generation at the national level and in isolated specific sites while there had not been a detailed study on small wind turbines for electrifying households at different off-grids part of the country. Small wind turbines for domestic power supply were commissioned from 1998 in the range of 100W – 2500 W while a 3MW grid connected farm was commissioned in 1999. Today wind energy is recognised as one of the main futuristic sustainable energy source to meet the energy demands of the country with good potential studies and private sector driven commercial power generation.

The approach adopted by Practical Action in promoting small wind turbine systems for power generation was a sandwich model between micro hydro village electrification schemes and biogas systems coupling the respective experiences. Small wind systems did not upscale as in the case of previously discussed appropriate energy technologies. While over 50 small systems have been used in the country, their sustainability is not proven. While factors such as wind being available in certain parts and pockets of the country including in the off-grid areas, existence of technical know-how and competent human resources with a potential to develop them further, availability of raw material in the local open market for producing components and this being a green technology, the overall energy cost being significant, rotating components needing frequent repairs and replacements, market and potential users being scattered and as a result economies of scale is hard to achieve, selection of not so suitable sites, unavailability of service providers and technical support in close-by areas and wind turbines needing fairly a large land area with no tall trees or other vegetation restricting farming and other development activities on land are some reasons for wind turbines not to get popularized.

Biodiesel

The interest for development and use of biodiesel in Sri Lanka has been closely linked to the world market price of petroleum diesel. A remarkable interest had been among the researchers, commercial establishments and government when the petroleum prices were high around 2006-2008 era although there had been a little interest during the global oil crisis in mid 1970s. Although several countries in the world have biodiesel programmes from grown energy plantations or used vegetable oil, the development and use that took place in Sri Lanka is insignificant.

The project intervention on liquid biofuels of Practical Action did consider only biodiesel leaving out popularly known liquid fuel ethanol and newly emerging Butanol. Biodiesel is a substitute for diesel while the other two are for petrol. Further, a model of producing biodiesel from dedicated community based energy plantation was tested in a village in the low county dry zone. Having conducted an investigatory study, the interventions were carried out in 4 inter connected phases. Each phase had some experts to assist from a panel of invited experts who served as an advisory board too.

The first phase was cultivation of biodiesel energy plantations. This was in the fences and home gardens as mixed crops. While seeds from oil bearing seeds such as neem, rubber, castor and jatropha were used in biodiesel producing experiments, only castor and jatropha were grown on soil for experiments. Both seeds and sticks were used for propagation, with about 7000 jatropha plants. Next phase was extracting the oils mechanically followed by transesterification of these oils into biodiesel. The final phase was using the produced biodiesel in different applications including power generation, water pumping and running a hand tractor. Some experts recommended jatropha to be promoted as an energy plantation as it could survive under harsh conditions including dry climate and infertile soil. There were shortages in jatropha seeds, particularly theseeds of higher quality.

The international market price of petroleum oils started dropping, so was the interest for biodiesel. Further, the cost of production from the community based biodiesel processing centre established by Practical Action was around Rs 300 per litre when the open market price of petroleum diesel was about Rs 110 per litre. The production cost was high due to smaller processing quantity and cost of input material being high. This community centre was capable of processing 5 litre of biodiesel per batch in about 2 hours of duration which is produced using about 25 kg of oil bearing seeds.

The interventions were not involved in making changes to the engine components. In one instance, the power generator crashed when biodiesel was blended in the ratio of 20% to 80% with petroleum diesel. This was rectified with a 10% to 90% ratio. Water pump and hand tractor worked well with blended proportion.

Energy plantation was not sufficient to meet the processing capacity of the centre. The requirements and marketing of biodiesel had also not been done extensively and therefore, with time, the amount of biodiesel processed reduced. The end of project activities did not see a suitable mechanism to sustain the community level biodiesel processing centre. By this time, the national level as well as global level interest on biodiesel had dropped with drastic drops in petroleum prices.

It was very clear that if continuous research and development could lead to good results as all the efforts were made by a team of well-coordinated local multi-disciplinary experts. Central coordination played a good role to bring the experts together frequently to share experience. However, lack of public interest and continued financial support clearly hindered further development.

Pico hydro systems

The hardships of people living in the hilly terrains with considerable rainfall had led them to find their own solution to meet their own energy demands. Using locally available knowledge and locally available material such as alternators of the motor bicycles and poly vinyl chloride pipes they have produced small scale hydro turbine and power generatorsin local workshops. By tapping the small water streams that flow through their land, they have produced electricity for domestic consumption meeting part of their energy demands, particularly lighting. At one stage around 2008, it had been estimated that there had been about 3,000 such locally designed and fabricated small pico hydro units. However, due to these being designed by different people of different levels of knowledge and local material in workshop with basic facilities, the quality and specifications of these have had a very wide range. Most of these had been of capacity less than 100 W with overall efficiency being less than 10%. The typical direct cost of such a system was less than Rs 5,000 while the people using the pico hydro systems were using inefficient incandescent bulls and hardly used efficient lighting devices such as CFLs or LEDs.

The intervention made by Practical Action was first to improve the turbine getting involvement of village folk involved in designing and fabricating these and the engineering interns with guidance from micro hydro practicing engineers. Next phase was to improve the power generator and safety aspects. This was important because the wiring from power generator to the house, distance of which at times exceeded 100m and internal house wiring were all done not according to acceptable standards. With the experience gained, further improvements were made to the overall pico hydro systems by the internal engineers and now the overall efficiency has increase to nearly 50%, but the overall cost has increased with improved efficiency, safety and professional inputs.

Key lessons learnt from these interventions include that indigenous knowledge of people are very vital and they have the capabilities to devise solutions to their own problems from their locality; their technologies can be significantly improvedwith some little external support; engineering interns backed by good guidance can make remarkable changes on ground; proper use of local resources are a key factor for success; although not captured by hydro resource assessments, there is a very significant number of potential sites for pico hydro power generation whether throughout the year or seasonal.

Hybrid systems

The UNEP funded Renewable Energy Village in Pattiyapola is the renewable energy related hybrid system well known to the energy society in Sri Lanka. This was in the mid-1980s with solar, biogas and wind energies. Practical Action too established a few hybrid systems including in Wenivelara with biogas and wind; Wind and solar in both Sooriyawewa and Kirinda; biodiesel and wind in Gurugoda. Wind-solar hybrid systems were for domestic use while the others were community schemes. All these systems demonstrated considerable technical and operations challenges where without the technical and mobilizing support from a centralized body is not available, the community could not use or manage them properly.

Conclusions

The preferences by people as sources of energy are dominated by electricity and liquefied petroleum gas. However, until the main grid electricity reaches a household, they tend to look for small scale decentralized renewable energy sources to meet their demands. Very often, these have not fully satisfied the energy consumers while using and managing these are far more cumbersome compared to grid electricity that directly reaches the houses or liquefied petroleum gas that could be bought from the market. While small appropriate energy technologies have partially met the energy needs, it has clearly shown a potential in further technology development with improved systems to be in place so that future energy challenges in the light of carbon foot print, global warming, climate change and depletion of natural resources such as petroleum and coal etc can be overcome using locally available natural resources by the local people.

At the introductory stage, it is necessary to assist the researchers and consumers with donor funding or government grants. However, these have to be evolved into community based solutions or commercial ventures. In a community approach, a considerable amount of mobilizing and financial or other material contribution by the community members is required. In the case of commercializing, smaller energy options have to be developed into an industry where there is a profit element for the market players supported with strong after sales services. Subsidies have to be reduced, if not removed for smoother promotion. People of Sri Lanka are capable of developing the technologies using skills, material, links, etc while knowledge and expertise have to be shared and pooled and well-coordinated to achieve synergy.

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Wave Manipulation for Near Shore Wave Energy Utilization

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Abstract

Sea waves may have a big potential to become a good source of renewable energy in Sri Lanka. This study is about concentrating very wide sea wave fronts into a tunnel so as to increase the velocity of flow and to generate electricity efficiently. It also concerns about diffusing the receding water, causing minimal impact to the near shore environment. A laboratory model will be tested for varying wave conditions and optimum parameters of the device will be determined. This approach will be verified using theory and computational fluid dynamics (CFD) tools. Suitable models of turbines will be tested with this device for quantifying efficiencies. The results and experience obtained through this study could be used in the future for designing a working prototype.

Key Words: Renewable energy, Kinetic wave energy, Wave manipulator, Wave energy conversion

Introduction

Hydro power, solar and wind are the main sources of renewable energy in Sri Lanka.In addition, the sea waves have a big potential to become a good source of renewable energy which is relatively inexpensive, reliable and environmentally friendly. There are at least 14 coastal regions in Sri Lanka, which may provide a considerable amount of electrical power. This paper carries forward the study reported in [1] and considers using the near shore waves for generating electricity by funnelling very wide sea wave fronts into a tunnel increasing the energy density. Additionally, the tunnel section stabilizes the water flow with respect to the wave length and the direction of flow. Afterwards, a suitable turbine mounted at the end of the tunnel converts the available energy of waves into mechanical energy. Then, a generator driven by this mechanical energy generates electrical energy. A diffuser section allows receding water to gradually decrease the remaining energy density. It also allows water to expand when the velocity decreases after losing some of the energy at the turbine.The main advantage of this manipulation is that it enables to utilize the wave energy over a distance of 100's of meters by using a turbine with dimensions in the order of some meters. Another advantage is that a wide intake can always acquire some waves given the statistical nature of sea waves. For example, waves of a certain width exist in a certain area for some time and then shift to the next area, either leftwards or rightwards, randomly.

The main purpose of this paper is to estimate the optimal dimensions for the concentrator and to select a suitable turbine for energy conversion.

Section 2 of this paper describes some theoretical developments which aid estimating the available energy, velocities and the enhanced velocity in the wave manipulator for sinusoidal waves such as those encountered in an artificial wave channel and for random wave crests encountered in the sea. Section 3 describes the development of a suitable model of the wavemanipulator for testing in the laboratory wave flume. Then, it illustrates the results obtained using CFD tools, analyzing the behaviour of water waves inside the proposed model. Section 4 briefly reviews the existing types of turbines and suggests a suitable type for this purpose. Sections 3 and 4 also present the test results of the wave parameters and the turbine performances obtained using this structure. Section 5 provides a conclusion.

Wave motion

In the literature[2], a water wave is considered to be sinusoidal with a wave length of λ, wave amplitude of a and a period of T. Then, the wave velocity which is known as the wave celerity, c, is given by

$$c = \frac{\lambda}{T} = \sqrt{\frac{g\lambda}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)} \qquad \text{Eq.1}$$

Where d is the depth of water,g is the gravitational acceleration. For deep water waves ($\lambda << d$) and shallow water waves ($\lambda >> d$), this reduces to $c = \sqrt{\frac{g\lambda}{2\pi}}$ and

$c = \sqrt{g(d+1.5a)}$, respectively. The celerity is the phase velocity with which an individual wave in a group moves. However, a group of waves seem to travel at a lower velocity referred to as the group velocity, *u*, which is given by

$$u = \frac{c}{2}\left(1 + \frac{2kd}{\sinh(kd)}\right) \quad \text{Eq.2}$$

Where the wave number *k* is $2\pi/\lambda$. For deep water, $u = c/2$ and for non dispersive shallow waves, $u = c$.

Wave energy is known to be transported at the group velocity. The amount of energy above the level of water at rest and per wave length can be given for the two cases separately. For small amplitude waves ($h = 2a << \lambda$), the total wave energy is the sum of potential and kinetic energies, which is given as

$$E = \frac{1}{4}B\lambda g\rho a^2 + \frac{1}{4}B\lambda g\rho a^2 = \frac{1}{2}B\lambda g\rho a^2 \quad \text{Eq.3}$$

Where *B* is the width of the wave and ρ is the density of water. This expression can be generalized for any depth.

For large amplitude deep water waves,

$$E = \frac{1}{8}B\lambda g\rho h^2\left(1 - \frac{\pi^2 h^2}{2\lambda^2}\right) \quad \text{Eq.4}$$

Note that this expression is the same as (3) for $h << \lambda$. This energy equation could be used if at least $d > \lambda/2$.

Momentum of the travelling sea waves

The cross section of a sea wave is most likely to have the shape of a raised-cosine function ora triangle as mentioned in[1].Then, these wave fronts occur in sequence with a gap of *s* meters and *n* times a second as illustrated in Fig. 1.Because the shapes can change from time to time in practice, any quantitative analysis would become approximate in the long run. Therefore, this sectionaims only to provide guidance in the design procedure.

Energy of a triangular wave front travelling at a velocity of *v* m/s with a momentum of *mv* may be given by

$$E_1 = 0.5mv^2 \quad \text{Eq.5}$$

Where *m* is the mass of the water in kg in the section of the wave being considered. Note thatthe travelling water column underneath the wave is considered separately next. Then, for the wave dimensions illustrated in Fig. 1,

$$E_1 = 0.5(0.5bhw\rho)v^2 = 0.25\rho bhwv^2 \quad \text{Eq.6}$$

Where ρ is the density of water in kg/m^3. In here, *w* is the width of the wave being considered. If all the dimensions are in meters, E_1 is in Joules.

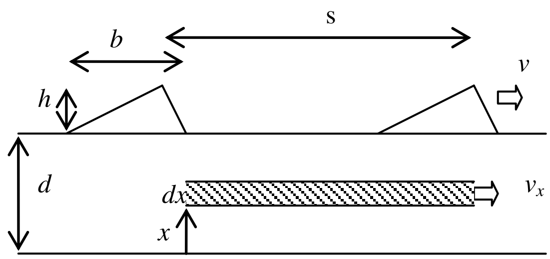

Figure1: Approximate profile of sea waves

If there are *n* wave fronts observed over a long enough time window of *T*, the total energy is given by nE_1. Therefore, the average power available can be given as

$$P_1 = \frac{nE_1}{T} = \frac{0.25n\rho bhwv^2}{T} \quad \text{Eq.7}$$

Therefore, the available power of a certain wave is proportional to the width, *w*. According to [1], any electro-mechanical apparatus which utilizes wave energy must have the dimensions in the order of 100's of meters, if they are to be useful in practice. This sets a practical limit to any attempts to utilize wave energy for generating mechanical or electrical power. For this reason, it is required to manipulate the waves such that their total energy is made available in a small area. Fig. 2 shows a structure that could be built in the near sea to funnel, tunnel and diffuse the waves. The funnel section concentrates very wide (w_1) waves into narrow waves (w_2), where $w_1 >> w_2$. The tunnel allows these narrow waves to stabilize, for example, with respect to the direction of the movement, velocity and the frequency. After this manipulation, the wave length and the velocity are to increase at the end of the tunnel reflecting the increase in energy density. Once the wave power is converted using an appropriate electro-mechanical assembly, the diffuser, which inverses the funnelling function,is to disperse the remaining power of the waves without flooding the shore considerably. In Fig. 2, b_1, b_2 and b_3 are the lengths of the corresponding sections.

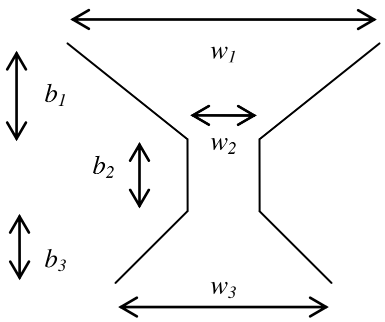

Figure2: Funnelling, tunnelling and diffusion

If the w_1 wide wave fronts are funnelled into a filtering tunnel of width w_2, the peak volumetric flow at the entrance to the structure (R_1) and in the tunnel (R_2), at wave peaks, are given in m^3/s by

$$R_1 = hw_1v_1$$

Eq.8

$$R_2 = hw_2v_2 \quad \text{Eq.9}$$

Where,$v_1$and v_2 are the corresponding velocities of the wave peaks.However, neglecting the reflections and eddies, R_1can be made equal to R_2. Therefore, the velocity of flow in the tunnel is increased approximatelyto

$$v_2 = \left(\frac{w_1}{w_2}\right)v_1 \quad \text{Eq.10}$$

If the depth of the sea-floor decreases towards the tunnel, v_2 should further increase.

According to normal observations, it is the case that there is a column of water underneath the waves, which also travels towards the shore, as illustrated in Fig. 1. Near the wave, this water column is likely to have a velocity similar to that of the wave but at a certain depth the velocity diminishes to zero. Assuming a linear velocity profile[1] shows that the additional power available in the tunnel is

$$P_1' = 0.125\rho w d v^3 \quad \text{Eq.11}$$

Although, there can be a few other parameters which influence the energy, power and the velocityestimated in this section, the purpose here is to consider the main form of sea waves.

A model of a manipulator

Theoretical research presented in the literature suggests that the wave length and the height of sinusoidal waves increase when the width of the channel decreases.

For example, [3] shows mathematically, that the wavelength should increase if the width of the channel decreases. By experimentally and numerically[4]it shows that the amplitudes of waves should grow in proportional to $w^{-0.5}$ in a converging channel. Here, w is the width of the channel. The wave magnitude should decay in proportional to $w^{-0.66}$ in a diverging channel. In this case, one of the walls of the channel is straight while the other one is slanting forward.However, no specific account on the behaviour of sea waves of the form shown in Fig. 1 in thestructure shown in Fig. 2 is available barring any further theoretical developments. Therefore, it is necessary to build a model of a concentrator for estimating the optimal dimensions, w_1, w_2, w_3, b_1, b_2 and b_3. These results can then predict the scale of a real prototype.

For example, if $\frac{w_1}{w_2}$ is too high, the level of energy concentration will be smaller than expected due to the increase in losses. At a certain very small $\frac{w_1}{w_2}$, a stagnation point occurs close to the tunnel entrance and the volumetric flow through the tunnel may become very small too. When $\frac{w_1}{w_2}$ decreases, the losses too decrease, increasing the velocity and the volumetric flow. In this way, the losses become smallest possible for no concentration, $\frac{w_1}{w_2}=1$, caused by only the surface resistance of the walls. Therefore, the model should enable to estimate the smallest tunnel width, $w_{2,opt}$, for which the losses are minimal and close to those of no concentration, for a givenw_1. In other words, this$w_{2,opt}$ and $w_1$should increase the velocity by keeping the volumetric flow and the energy as close as possible to that of the original waves captured by the funnel section. The tunnel width, $w_{2,opt}$, is then the major dimension of the turbine.

Model development and testing

Laboratory model

The model of the manipulator mainly consists of three parts, funnel, tunnel and the diffuser. This was constructed using Aluminum for minimizing frictional losses and enhancing the durability. The width of the tunnel could be adjusted by sliding the walls. The funnel and the diffuser were joined to the tunnel by using hinges so that the angles could be changed easily.

Fig. 3 shows the isometric view, side elevation and the plan of the model. All dimensions are in meters.

Simulation using Delft3D

Delft3D is a modular open source code developed by Deltares [5], and provides an integrated framework for a multi-disciplinary approach, creating 2D and 3D computer simulations of waves and tides in the coastal areas. Therefore, first, the model of the wave manipulator was simulated using Delft3D. This structure was selected as an obstacle placed in the large wave flume. The simulation was performed for different angles of the funnel (α) and the diffuser (β), and for different tunnel widths (w_2) for a certain incident wave. The

MATLAB was used to process the results and to obtain the wave parameters in the manipulator.

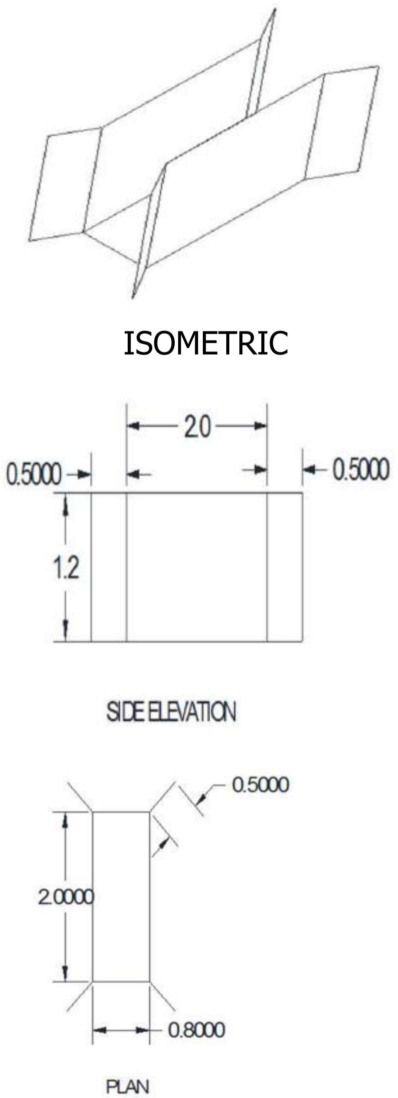

Figure 3: Drawings of the model manipulator

For an incident wave having a wavelength (λ_1) of 1.3m, height (h_1) of 0.34 m and a period (T_1) of 1.2 s, Table 1 shows the wave parameters in the tunnel, obtained through the simulations forw_2=400 mm and β=45^0.

According to these simulations, the wave length(λ_2) and the wave height(h_2) in the tunnel, for which the wave energy corresponds to, are highest for α=45^0. In addition, Table 2 lists the enhancement of energy density (e_{in}/e_t)in the tunnel suggesting that it corresponds to the funnelling ratio, $\frac{w_1}{w_2}$ except for highα. This is because the incident wave reflects off the walls of the funnel opposing the oncoming waves rather than directing into the tunnel, when α is high. Note that energy of the incident wave (E_{in}), that in the tunnel (E_t) and the energy loss (L=E_{in}-E_t) are given in Joules.The energy density (e), which is the amount of energy per unit width of the wave, is given in Joules per meter.

Table 1: Simulation results for w_2=400 mm

α	w_1 (mm)	h_2 (m)	λ_2 (m)
30^0	900	0.38	2.20
45^0	1107	0.40	2.25
60^0	1266	0.34	2.20

Table 2: Energy density for w_2=400mm (through simulations)

w_1/ w_2	α	E_{in} (J)	E_t (J)	L (J)	e (J/m)		e_{in}/ e_t
					e_{in}	e_t	
2.3	30^0	166	156	10	184	389	2.1
2.8	45^0	203	176	27	184	441	2.4
3.2	60^0	233	124	109	184	311	1.7

Testing in the wave flume

The physical model was partially submerged in the large wave flume, which is 30 m long, 1.80 m wide and 2.10m deep, and consists of smooth concrete walls, as illustrated in Fig 4. In order to avoid the impact of reflecting waves, it was located a reasonable distance away from the wave breaker at the end of the flume.

With the plunger type wave maker, the same incident wave used for simulations, was generated for testing. The measured wave parameters in the tunnel are given in the Table 3 and Table 4.

Figure 4: Photographs of the model manipulator in the flume

Table 3: Measured parameters for w_2=0.25 m

α	w_1 (m)	h_2 (m)	λ_2 (m)
30^0	670	0.38	2.7
45^0	957	0.45	2.6

Table 4: Measured parameters for w_2=0.45 m

α	w_1 (m)	h_2 (m)	λ_2 (m)
30^0	860	0.39	1.8

The energies of the incident wave (E_{in}) and that in the tunnel (E_t) were calculated from (4), for small amplitude waves, using the data in Table 3 and Table 4. Table 5 and Table 6 include the corresponding energies (E_{in} and E_t), the energy losses (L) in the concentration and the ratios of the increase in energy density (e_{in}/e_t) in the tunnel.

Table 5: Energydensity for w_2=0.25 m (through testing)

w_1/ w_2	α	E_{in} (J)	E_t (J)	L (J)	e (J/m)		e_{in}/ e_t
					e_{in}	e_t	
2.7	30^0	123	119	4	184	476	2.6
3.8	45^0	176	161	15	184	644	3.5

Table 6: Energy density for w_2=0.45 m (through testing)

w_1/ w_2	α	E_{in} (J)	E_t (J)	L (J)	e (J/m)		e_{in}/ e_t
					e_{in}	e_t	
1.9	30^0	158	151	7	184	336	1.8

According to these results, the loss in the energy concentration process is less than 10%. The ratio of the energy density increase in the tunnel is almost equal to $\frac{w_1}{w_2}$. The free movement of the waves in the tunnel, which is kept open for taking measurements, allows not only the wave velocity but also the wave height to rise. Therefore, the velocity increase is not as high as that predicted in (10). The increase in energy density in the tunnel is represented by the corresponding increases in both the velocity and the height of the wave.

An optimal turbine for the concentrated near-shore waves

There are two types of devices which are used for the utilization of sea wave energy. The floating and non-rotating energy converters such as attenuators or absorbers are mainly used for converting the power of surface waves. However, rotating devices such as turbines are mainly used for extracting tidal energy and those are installed under water[6].

Out of the non-rotating type devices, the Pelamis sea snake which consists of several sections of cylinders connected by hinges can generate about 500 kW. Such a device has a diameter of a few meters and extends a few hundred meters into the sea rather than along the coast line.

The available types of turbines fall into three categories, namely reaction turbines, impulse turbines, and free-flow turbines.

(a) Reaction turbines

These turbines translate the pressure head of water into kinetic energy by using appropriate rotor blades, and vanes which guide water flows. When the water leaves the rotor, the reactive forces cause it to rotate. Typical examples are Francis and Kaplan turbines mainly used in inland hydro power stations which keep high head waters in reservoirs. They normally extract hundreds of megawatts.

(b) Impulse turbines

These turbines produce mechanical energy by using the kinetic energy of the water. Therefore, a suitable device converts the pressure head of the water into a high speed jet which impinges on the blades of the rotor resulting in rotations. A typical example is Pelton-wheel turbine which can also extract hundreds of megawatts. The efficiency (water to turbine shaft) can reach 100% when the rotor velocity is half of the velocity of the water-jet[7]. In a practical implementation, a Pelton-wheel turbine generated about 45 MW with a 114 m/s jet resulting in a volumetric flow of 7 m^3/s. This sets the rotor velocity to be 56 m/s which was slightly below half of that of the jet.

(c) Free-flow turbines

There are several types of free-flow turbines which extract the kinetic energy of tidal currents and river flows[8]. For example,

Horizontal axis turbines:These are similar to both the propeller type with narrow blades and the fan blade type with wide blades. In these cases, the water flows parallel to the axis of the turbine and impinges on the plain of rotation. The propeller type, whose blades have the shape of an aerofoil, depends on the lift force on each blade while the fan blade type seems to use the reactive force as well as the impulsive force. According to the theoretical predictions and simulations, these types seem to have an efficiency of about 50% at a tip-speed-ratio (TSR) of about 2, which is the ratio of the tangential velocity of the tip of the rotor and the velocity of water flow. The typical velocity of flow considered is in the range of 1 to 3 m/s resulting in an extracted power of close to 1 MW.

Vertical axis turbines:For example, the blades of Darrieus turbine have a uniform cross section, similar to that of an aerofoil and are vertically mounted around the shaft which is also vertical. Therefore the water flows in a perpendicular direction to the axis of the turbine. Darrieus turbine depends on both the lift force and the drag force and has a maximum efficiency of 43% at a specific TSR close to 3.5. Over the range of 1 to 3 m/s velocity, it has reached an efficiency of 35% in a practical implementation.

Golov turbine with twisted blades is somewhat similar to Darrieus turbine but the blades are not vertical and straight due to twisting. This provides a maximum efficiency of about 25% at a TSR of about 2 and a velocity of 1 to 3 m/s. However, Golov turbine and some variants of it can function in the horizontal-axis mode too. For example, the Savonius turbine is similar to Golov but the blades are wider and extend to the shaft. Some report that by cascading several of these rotors, it is possible to intercept very wide flows. In some instances, both the Darrieus and the Golov type have extracted some hundreds of kilowatts.

Water-wheel: This turbine has rectangular blades connected to the hub using struts[9]. This is a horizontal axis turbine and the axis is perpendicular to the direction of flow. Normally, one half or even less is under the water while the rest is over the surface of the water. Curvier blades may extract more impulsive energy. Blades having the shape of an aerofoil may use both the impulsive force and the lift force increasing the efficiency further.

However, none of these free-flow turbines have been tested in high speed flows. No theoretical simulation or empirical data were found to ascertain their functionality and the strength of the body structure in a dense liquid flowing at any higher speed than 10 m/s.

In this project, the flow is neither a one with high head nor a free flow type because the sea waves are funneled into a tunnel. At the end of the tunnel, the flow has a high velocity head and a high wave length which fluctuates within a certain limit. For example, a wave front traveling at 2 m/s would yield a velocity of 40 m/s ideally, if the funneling ratio is 20, neglecting the losses. Note that this resembles a case where a certain high head of water (or the wave power) has been already translated into a flow with high velocity head, externally. Therefore, a turbine that has the properties of both the impulse type and free flow type may extract the highest power. According to this argument, the Pelton-wheel, the water-wheel or a combination of them may be the optimum type. Since, the horizontal axis turbines with wide blades (fan type) provides a high efficiency in free flow channels according to the literature, testing will include this type too.

Testing with horizontal axis turbines

Two fan blade type horizontal axis turbines with the diameters of D_1=0.18 m and D_2=0.38 m were constructed for this purpose. Then, the smaller one was installed at the rear end of the tunnel by keeping w_2=0.25 m.For the same incident wave, the brake torque (τ) and the angular velocity (ω) were measured. Table 7 shows the measured values for two funnel angles. The procedure was repeated with the larger turbine by setting w_2 to 0.45 m.

Table 8 shows the measured values for one of the funnel angles, for this case. Fig. 5 shows two photographs of these turbines in the wave manipulator.

Figure 5: Turbine placed in the tunnel end

Table 7: Turbine measurements (D_1=0.18m)

α	w_1 (m)	w_1/w_2	τ (Nm)	ω (rpm)
30^0	670	2.7	1.3	1205
45^0	957	3.8	1.5	833

Table 8: Turbine measurements (D_2=0.38m)

α	w_1 (m)	w_1/w_2	τ (Nm)	ω (rpm)
30^0	860	1.9	15.6	-

Note that 0.18 m turbine, with a small capture area, intercepted only a part of the available energy because the wave height for this case was higher than 0.38 m. Otherwise, the brake torque and the angular velocity could have been much higher. However, 0.38 m turbine could capture most of the energy of 0.39 m high waves in the tunnel. This increased the brake torque by a factor of about 12.

Conclusions

A sea wave energy concentrator for electricity generation was tested using CFD simulations and a laboratory model. Simulations suggested that the energy density ratio is increased for high funnelling ratios and small funnelling angles. Laboratory testing with the model manipulator confirmed that the increase in energy density is proportional to the funnelling ratio. With the horizontal axis turbines, the higher the capture area, the higher the brake torques. The experiences gained through this project are useful in designing a real scale working prototype.

Acknowledgments

We acknowledge the support received from the staff of the workshops of the department of production engineering and electrical engineering, faculty of Engineering, University of Peradeniya. We also acknowledge the service of the staff of the fluid mechanics laboratory of the same faculty. We are grateful to Tokyo Cement Company (Lanka) PLC for providing the financial support.

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The Reality of Development and Second Law of Thermodynamics

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Abstract:

Objective of this paper is to study the reality of sustainable development. It is important to study the sustainability of development and to evaluate the possibility of achieving it before the sustainability of its driving mechanism, which is energy, is evaluated. Atpresent the measures of the development are evaluated by energy indicators and environmental indicators, like energy intensity and carbon foot print. Today issues like resource scarcity and other environmental issues are to be assessed by these indicators whereas the inability to quantify the impacts of development using these indicators is considered as a nonstandard practice among the scientific community. Evaluation of the present global impacts due to development using these physical indicators which assess the material impact is questionable. Therefore it is to study the reality of evaluation of development using these indicators and to shift the development and energy from these narrow limits.

Key words: Development, Sustainability,Energy,Exergy,Resources

Introduction

Development is the most important goal to be achieved by the global community today. The driving mechanism or the power of the development is exergy because every process requires exergy. Numerous indicators are used to measure or compare the status of development referenced to time and different countries. These indicators are used to measure different aspects of development i.e. social, environmental, economic and technological. Since exergy is the driving mechanism of development, indicators which evaluate the sustainability of exergyhave become more important. Since the results of development have made irreversible changes on the earth it is more important to evaluate the sustainability of development than the sustainability of its driving force exergy.

Exergy

The main constituents of our body and environment around us are matter(mass) and forces. The main types of forces are gravity, electromagneticand forces among atoms or molecules at micro level.Forces which we apply by our muscles are created by such micro level forces. When these forces (F) are acting on some mass, the mass is moved by small displacement vector(dr). The term F.dr is known as the work done on that mass by F. Then the total work done is $\int F.dr$(This is energy).Now by using the relevant basic equations of the above said forces it could be shown that for a system including all the above said forces (withoutfrictional, resistive effects)

$$\sum F_i.dr + \sum \frac{1}{2} m_i v_i^2 = constant \quad \text{Eq.1}$$

F_i = Force of i^{th} component the system
m_i= massofi^{th} component in the system
v_i= velocity of i^{th} mass

This is the energy conservation law at macrolevel(neglecting the frictional effects).But it is well known that in all such systems heat is generated and equation (1) does not hold perfect. With this experience it was concluded that some amount of energy is converted to energy at micro level which is responsible for the rise in temperature of the related masses. Then the energy is conserved with this new energy term which was identified as the internal energy of matter and later it was revealed that it consists of two parts at microscopic level, i.e. potential energy due to force fields in molecules or atoms and kinetic energy due to kinetic energy of atoms or molecules. Kinetic energy per degree of freedom of atom or molecule is responsible for the property of temperature.

With this new energy although the concept of conservation of energy was extended to micro level(1^{st} law of thermodynamics) experiments with heat engines and various other activities related with heat (temperature) it was later revealed that this internal energy specially the kinetic energy part cannot be manipulated as we wish.i.e. although we can convert the kinetic energy of a tennis ball totally to some other form of energy the kinetic energy of atoms or molecules cannot be converted totally. This was the specialty of this new form of energy. It was this speciality which originatedthe 2^{nd} law of thermodynamics, which is interpreted in various forms.

(1) Kelvin- Plank statement– No process (cyclic) is possible whose sole result in the conversion of heat completely in to work. In other words it states that no process is possible by which an amount of heat is absorbed by a source at a particular temperature and converts it totally to work without releasing some amount for a thermal sink below the temperature of the thermal source.

(2) Clausiusstatement:No process is possible whose sole results in the transfer of heat from a colder to a hotter body without any external effort. (2) could be derived from (1)

Now by using (1) and a reversible cyclic process it could be shown that any cyclic reversible process taking place between the temperatures (T_1, T_2, $T_1>T_2$) will share the same thermal efficiency (η) (work out put per unit heat absorbed by heat source). Engineer cannot developed a thermodynamic reversible cycle using ideal gas working between two heat source/ sink at temperatures T1 and T2 and showed that the thermal efficiency was $\eta = (1-(T_1/T_2))$. Therefore this η is the maximum thermal efficiency for anreversible engine working between temperaturesT_1 and T_2.

The concept of exergy was evolved within the above background. The Greek word 'ex' which means outer and 'ergon'which means force or work [1]. Exergy of a material is the maximum work (pdv, electrical, etc.) that could be taken from the material, when it is taken to a relevant reference state from its existing state. When energy is referred to total work, exergy is referred to the useful work. Therefore not all the energy in the world is exergy.Exergy is the form what we are benefited from when we perform the activities of development. Exergy is also a measurement of the quality of energy. According to above statements related to second law of thermodynamicswhen a cyclic process occurs (transferring heat from a reference source/ sink at constant temperature which is usually the atmospheric temperature,) if it is thermodynamically irreversible, some exergy has to be spent on this process.

Before fossil fuel era

Before fossil fuel era almost all the processes were cyclic. The exergy received from the sun is the main source for overcoming the irreversibility produced during these processes. The exergy received from the sun is absorbed by the trees and converted into food to be consumed by the animals and humans which is in turn converted to muscle power or trees are burnt directly to produce exergy. In addition the exergy from the sun is stored as the exergy in the wind and water. This system was driven in cyclic manner by the energy (then converted to exergy) received from the sun. Sustainability of the system is assured by the cyclicity of the system. Existence of this system is determined by the existence of the sun. The ancient water management system is presented in Figure1 and Figure2,which describes the cyclicity model related to the same water management system.

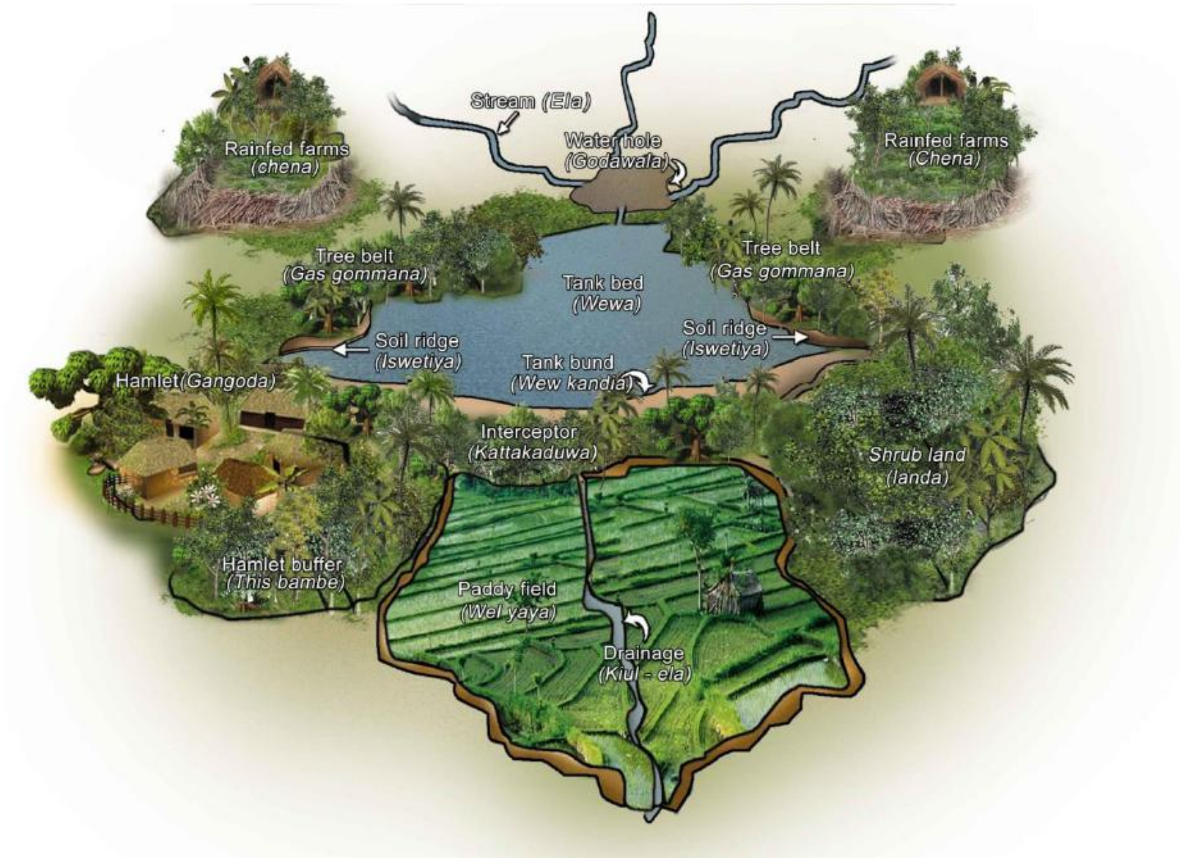

Figure 1: Ancient Wew Gama– A typical system within the cyclicity(Drawn by Dr. P.B. Dharmasena)

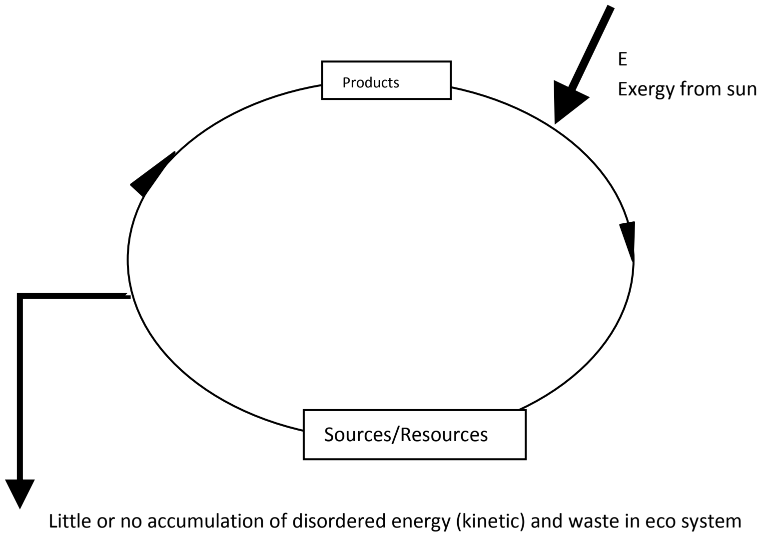

Figure 2: Cyclicity model for the activities invention of fossil fuel

Exergy and Development

Exergy is the useful energy which is used for almost all the activities around us.According to whatever the way we need, Internal energy of materials cannot be used likewise. Therefore, without exergy most of our day-to-day activities taking place with the modern development paradigm will be impossible!

Our earth ecosystem is almost a closed system. Apart from radiation from the sun, we are isolated. Radiation of the sun gives exergy to the ecosystem, basically by producing fuel and food $(\text{Fuel} \xrightarrow{combustion} \text{exergy})$, $(\text{Food} \xrightarrow{cellbiologicalreaction} \text{Exergy})$, activating hydro cycle (*hydro power (exergy)), activating wind cycle (wind power (exergy)), activating solar cells (electrical energy), etc.

Ecosystem of earth is a thermodynamic cycle producing exergy (work) by absorbing heat at higher temperature (near ground surface) and releasing heat to outer space at lower temperature (in upper atmosphere). So until the invention of fossil fuel, people lived/worked with this exergy. Apart from the exergy gained by sun the system was almost cyclic, i.e., it was sustainable (the most important parameter for sustainability of a closed system is its cyclicity!).

Invention of fossil fuel

Established idea among the world is that humans are in a process of development since they have first appeared on the earth. In this process of development resources are consumed continuously and we are progressing along a linear path. Once the fossil fuel was discovered

the process of development began to proceed at a speed that has never been. Fossil fuel contains high exergy which has been consumed to do work.
After the invention of fossil fuel tremendous amounts of exergy is released and people use this exergy to perform many activities out of which most are completely irreversible (Figure 8). In addition large quantities of natural resources were consumed within this process of development. The usage of exergy has produced disordered energy which is kinetic energy at microscopic level that has accumulated in the ecosystem. The materials used have been converted into waste at the end of their usage.

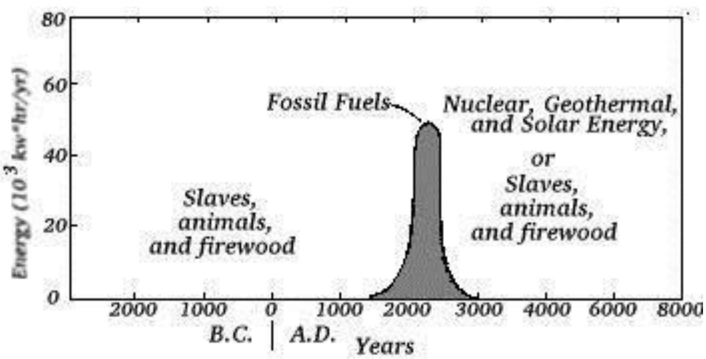

Figure 3: Fossil Fuel Consumption with Time

(Source-http://www.earthsci.org/education/teacher/basicgeol/fossil_fuels/fossil_fuels.html)

A thermodynamically irreversible process could be reversed by using exergy.Today exergy in fossil fuels is used to do changes (physical) to cater to five senses. Once fossil fuel is over these changes will come back to their stable modes and no exergy will be there to re-change them. At this stage it is very doubtful even whether the good-old solar powered natural cyclic system will work.
The permanent changes that have been done to the eco system cannot be recovered by exergy.Once the biological systems - soil, water and air has been polluted,it will not bepossible to reinstate the purity of them using exergy. The figure 4 shows the fossil fuel based infrastructure at present world.

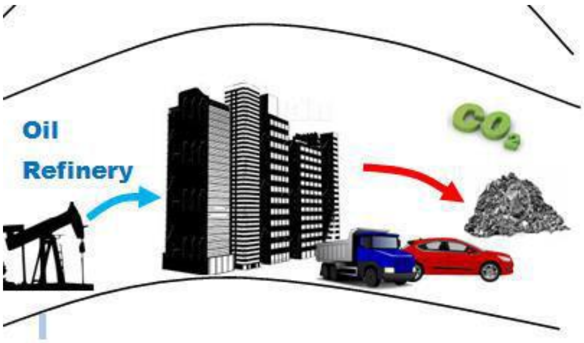

Figure 4: Fossil fuel based infrastructure in modern world

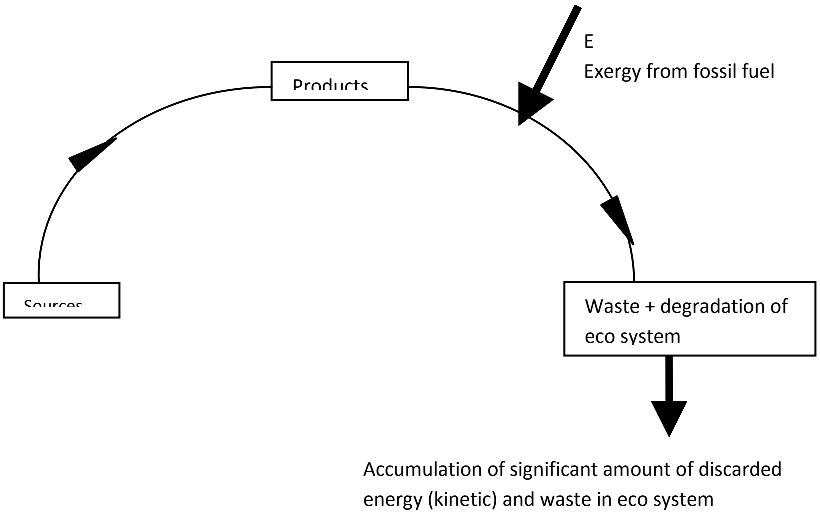

Figure 5: Accumulation of disordered exergy and waste in the ecosystem after the invention of fossil fuel

The 2nd law and the idea of exergy coming under it is a very important concept in understanding the paradigms of sustainable development. Until now no technology has been developed to overcome the limitation layed down by the 2nd law. When whole of the ecosystem is taken into consideration all the modern technologies rapidly decreases the exergy in the system by producing irreversible results as illustrated inFigure 5.

Theoretical Exergy from the Sun

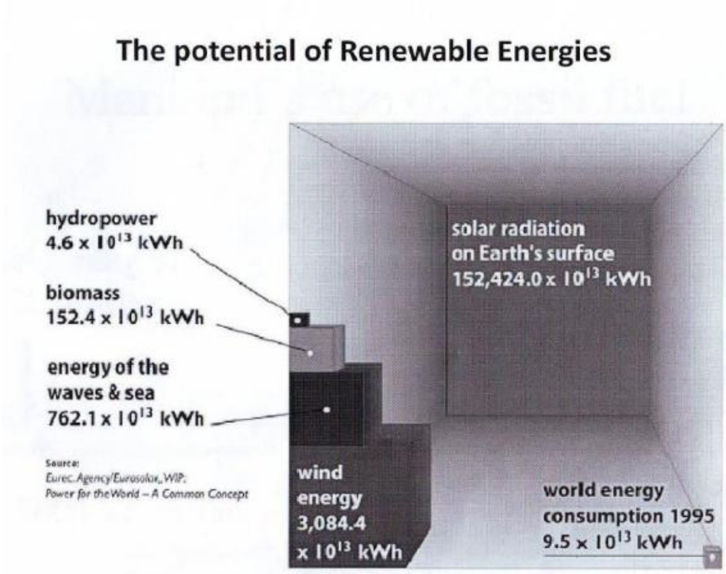

Figure6: The Potential of Renewable Energies

(Source-Eurec.Agency.Eurosolar, WIP. Power for the World- A Common Concept)

Above figure shows the annual energy requirement and the energy received from the sun. It also shows the existing renewable energy potential which is much larger than the energy requirement.

Below equation shows the theoretical estimation of sun's radiation received by earth using blackbody radiation and Carnotefficiency.

$$\eta_{max} \equiv \frac{W_{max}}{\sigma T^4} = 1 - \frac{4T_o}{3T} + \frac{1}{3}\left[\frac{T_o}{T}\right]^4 \qquad \text{Eq.2}$$

η_{max} = Maximum conversion efficiency from radiation energy to work

W_{max} = Maximum work

T_o =Reference environment temperature (Temperature of an atmosphere)

T = Temperature from heat source (Temperature of sun)

When the actual temperature values are substituted, η_{max}~ 93%. Therefore a large amount of exergy is available from the sun! But to extract such exergy it will be needed to install solar collectors covering almost all the sky and huge amount of Carnot type engine will be needed; and also the releasing heat will definitely increase the temperature of ecosystem. Then this will affect the whole ecosystem. Therefore if we try to extract that amount of exergy from the sun, ultimately we will end with exergy (F.dr) without life on earth. Then the vital question is the optimum extractable exergy from sun?

This question has to be answered by studying the civilization which prevailed before the fossil fuel era. Various definitions, calculations made within this fossil fuel era will not give a clear answer to this. Because almost all the calculations and definitions are based on fossil fuel scenario. For example, today people talk about 20% renewable energy in 2020! Now the immediate question is for how long? Even with the existing technology and exergy from fossil fuelwe can theoretically convert the whole world to run on renewable i.e. all the required infrastructure could be developed. But how long will this infrastructure made to suit the renewable will work without supporting exergy from fossil fuel? This is the vital question.

For a short period of time we may be able to manage our exergy requirements to perform current development activities from renewables. But could it be long lasting – sustainable. Therefore exergy analysis alone will not be sufficient to get an idea about sustainability. Exergy analysis will only provide a timely – day-to-day possibility of such activities. Sustainability is connected with cyclicitytoo. Therefore the two criteria to be analyzed in performing an activity (in the name of development) are exergy balance and cyclicity. The process/ activity should be cyclic and the exergy to perform this cyclic process should be providedby the day-to-day energy of sun. Cyclic nature will ensure that no accumulation of waste will take place continuously and no degradation of ecosystem. Exergy usage from day-to-day sunlight will ensure that no continuous depletion of exergy derived by fossil fuel (which is non cyclic) hence no continuous accumulation of disordered energy (heat) in the ecosystem.

Many of the activities occurred before fossil fuel era,werein good agreement with above criteria (Figure 7). Human exergy and animal exergy had been used extensively (ancient massive soil brick constructions) and also hydro, wind have been used within the same scenario (Samanalawewa iron smelting). Their civilization had prevailed for very long periods compared to the existing fossil fuel era!

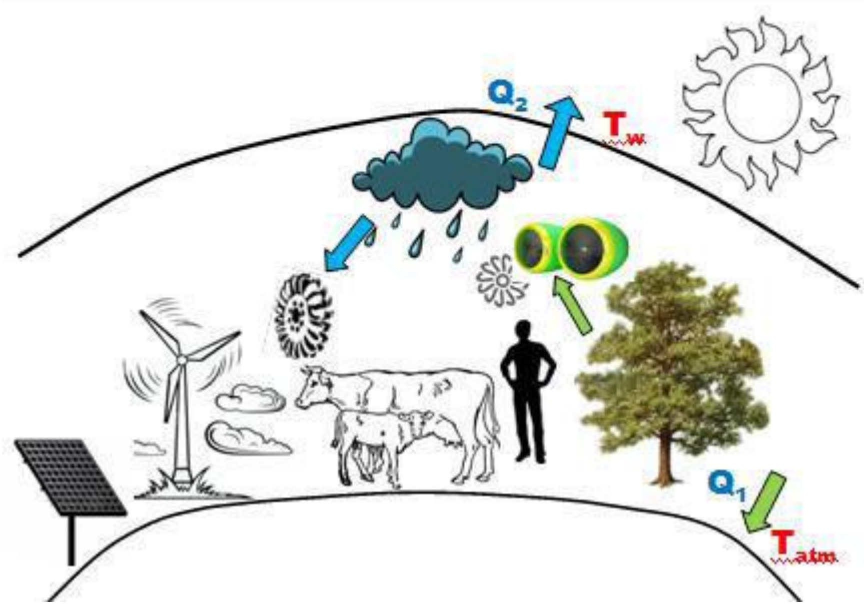

Figure7: Usage of renewable energies within the limits of cyclicity

Conclusion

Concept of exergy which is derived from the second law of thermodynamics can be used to understand the processes around us. Before the discovery of fossil fuel the changes done in the environment and thermodynamic irreversibilities were recovered by the exergy of the sun.

At present the changes done in the environment and the thermodynamic irreversibilties due to fossil fuel based platform is unable to be recovered through the exergy of the sun. Therefore as a solution for these problems civilization before the discovery of fossil fuel should be studied where the activities were within the cyclicitylimits of nature andwhere the irreversibilities can be recovered through the exergy of sun.

The final argument which this paper tries to put forward is that the current activities taking place in the name of development cannot be sustainable and this is not a problem of technology instead an inherentcharacteristic of nature which is well stated in the second law of thermodynamics and in the well known argument that the main criteria for sustainability of a close system iscyclicity.

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Optimization of Life Cycle Cost of Buildings in terms of Envelope Elements through Combined Performance Modelling and Generic Optimization

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Abstract:

Life cycle cost is one of the criteria for assessing the performance of buildings. According to the U.S. Department of Energy, building envelope is responsible for 25% of energy usage and accounts for 15-40% of the total construction cost of the building. Hence it makes sense to optimize the building life cycle cost through an efficient building envelope design. However, the best combination of the building envelope elements for optimizing the life cycle cost of buildings is difficult to be determined and is not known. Life cycle cost analysis is mostly done through building performance modelling tools. However, this is a slow and a tedious process, and generally only a few cases are evaluated in a large range of possible scenarios. By combining a generic optimization scheme with building performance modelling, the best combination of building envelope elements can be determined and, thereby, it is possible to optimize the life cycle cost of buildings successfully subject to predefined constraints. This paper describes how the life cycle cost of an office building located in the suburbs of Colombo is optimized in terms of building envelope elements through combined performance modelling and generic optimization. The optimal envelope design reduces the annual energy consumption substantially, leading to an optimal life cycle cost of the building while creating a better thermal environment for the occupants.

Keywords: Life cycle cost, Envelope elements, Performance modelling, Generic optimization

Introduction:

Buildings account for nearly 40% of the global energy consumption, 16% of the world's fresh water, 25% of the forest timber, while emitting almost 70% of oxides of sulphur and 50% of carbon dioxide gas annually [1]. Presently high emphasis is given to the reduction of energy consumption and life cycle cost by optimizing the performance and resource utilization of buildings.

A building is a complex system with multiple interacting physical processes taking place simultaneously. Different aspects influence the performance of buildings, and building envelope is one of the major contributors in this regard. Building envelope is the interface through which interactions between indoor and outdoor environments takes place. According to the U.S. Department of energy [2], building envelope is responsible for approximately 25% of energy usage in buildings. It can increase up to 42% in the residential sector and 57% in the commercial sector. Building envelope also accounts for 15-40% of the total construction cost and can contribute to an additional 40% cost when impacted by building services [3]. Hence it is evident that the decisions made on the building envelope during the conceptual design stage have substantial impacts on the performance of buildings. The choice of building orientation, aspect ratio, window-to-wall ratio (WWR), location and types of fenestration, envelope materials and their characteristics, glazing and shading aspects, etc. can have a major impact on the annual energy consumption and life cycle cost of buildings. Simply making buildings in the right shape and the correct orientation can reduce the energy consumption by 30-40% at no extra cost [4]. However, the best combination of the aforementioned envelope elements for optimizing the performance of buildings is difficult to be determined and is not known mainly due to the existence of complex nonlinear relationships among different envelope elements. Finding a solution to this problem can be implemented through the analysis of building performance in terms of its envelope elements, which is the main task of the present work.

Performance of buildings can be analysed based on the following criteria:

- Energy performance
- Indoor environment for human comfort and health
- Environmental degradation
- Economic aspects

Building performance modelling is mostly done through energy modelling. This is an approach that analyses thermal aspects, day-lighting, moisture, acoustics, airflow and indoor air quality of buildings [5]. A whole building energy simulation tool can serve this purpose. However, building energy modelling is generally carried out on a scenario-by-scenario basis, where the designer generates a solution and subsequently utilizes the computer to evaluate it. The process is generally implemented by changing one envelope variable at a time while keeping all other variables constant and then making a comparison between the new envelope design and the base design related to the performance of the building. Hence, it is a slow and a tedious process and generally, only a few cases are evaluated in a large range of possible scenarios. As the number of envelope variables increases, the process becomes even more difficult and cumbersome and it often becomes difficult to understand the impact on the building performance due to the existence of nonlinear relationships among the variables. Also, there is every possibility that the designer ends up with only a sub-optimal envelope design. Although many building simulation tools have been developed, the inherent trial and error procedure adopted for the improvement of the building performance is still a time consuming and ineffective task because of the difficulty in handling a large solution space. Hence, instead of evaluating the building performance with respect to individual envelope elements, changing one at a time, it is necessary to consider a strategy for optimizing the building performance through an integrated approach.

On the other hand, process of building performance optimization is carried out to determine the optimum value of an objective function such as building Life Cycle Cost, by operating an appropriate optimization algorithm through an iterative process. This involves computing the objective function value and comparing it with that of the same at the previous iterative step, until an optimum of the objective function is achieved. Generally, objective functions found in building performance problems are highly nonlinear and complex in nature and hence cannot be readily solved [6]. However, whole building simulation tools are capable of evaluating such complex nonlinear functions with their advanced solvers and hence can be readily used to evaluate the aforementioned objective functions. Furthermore, the optimization tools have the capability of varying the design variables simultaneously during the optimization process, which is not a feasible task during energy modelling with whole building energy simulation tools.

Hence, it is clear that both energy modelling and generic optimization, when applied in isolation are not very effective tools since they have their own limitations and drawbacks. However, if they are integrated in a common platform, the respective tools can operate hand in hand by combining their strengths for establishing an efficient building performance optimization process. On this basis, by combining a generic building performance optimization scheme with a whole building simulation tool, it is possible to optimize the performance of buildings successfully by determining the best combination of building envelope elements, subject to predefined constraints. This paper describes how this approach can be implemented for optimizing the life cycle cost of an office building located in the suburbs of Colombo in terms of its envelope elements.

Objective Function

In an optimization problem, objective function represents the aspect to be optimized, subject to predefined constraints. During the present analysis, Life Cycle Cost (LCC) of the building is considered as the objective function. To be more precise, difference in building Life Cycle Cost ($dLCC_j$) between the Life Cycle Cost of any envelope design (LCC_j) and that of the existing base design (LCC_0) is taken as the objective function to be optimized. Hence the objective function is given by:

$$f(x) \cong dLCC_j = LCC_j - LCC_0 \quad \text{Eq.1}$$

$$f(x) \cong dLCC_j = \sum dIC_j + \sum dOC_j \quad \text{Eq.2}$$

Where,

dIC_j - Difference in investment cost of any specified building element/component in a particular envelope design and that of the existing envelope design (Rs.)

dOC_j - Present Value (PV) of the difference in operating cost of a certain item between a particular envelope design and that of the existing envelope design, occurring at a particular point in time during the lifetime of the building (Rs.)

$$\sum dIC_j = dIC_{walls} + dIC_{windows} + dIC_{HVAC} \quad \text{Eq.3}$$

Where,

dIC_{walls} - Difference in investment cost with respect to walls

$dIC_{windows}$ - Difference in investment cost with respect to windows

dIC_{HVAC} - Difference in investment cost with respect to Heating, Ventilation and Air Conditioning system

$$d = \frac{D - I}{1 + I} \quad \text{Eq.4}$$

Where,

d - Real discount rate

D - Nominal discount rate

I - Rate of inflation

$$\sum dOC_j = \sum_{1}^{n} \frac{(1+e)^j E_p (dE_j)}{(1+d)^j} \quad \text{Eq.5}$$

Where,

E_p - Current price of electrical energy (in the base year) (Rs./kWh)

dE_j - Difference in annual electrical energy consumption between a particular envelope design and that of the existing envelope design occurring at a particular point in time (kWh)

e - Annual rate of escalation in electrical energy price

n - Lifetime of the building (yrs.)

Hence, the objective function becomes:

$$f(x) \cong dIC_{walls} + dIC_{windows} + dIC_{HVAC} + \sum_{1}^{n} \frac{(1+e)^j E_p (dE_j)}{(1+d)^j} \quad \text{Eq.6}$$

Whole Building Simulation Tool:

Energy Plus [7] v. 8.0 is used as the whole building simulation tool during present work. It is a new generation building energy modelling tool based on DOE (U.S. Department of Energy) – 2 and BLAST (Building Loads Analysis and System Thermodynamics), with numerous capabilities and was first released in 2001. It can model heating, cooling, lighting, ventilation, other energy flows, water usage etc. in buildings and includes many innovative simulation capabilities [7].

Optimization Tool

GenOpt [8] v. 3.1.0 is used as the optimization tool in the present analysis. *GenOpt* is a generic optimization program whose main field of application is building energy usage or operating cost optimization. It can be combined with any whole building simulation tool that reads its input from text files and writes its output to text files [8]. *GenOpt* automatically finds the values of user defined independent variables that minimize the objective function. The independent variables can be continuous variables (possibly with lower and upper bounds), discrete variables or both. *GenOpt* initiates the simulation task, checks for possible simulation errors, reads the value of the objective function to be minimized from the simulation output file and then determines the new set of input parameters for the next run [8]. The process is repeated iteratively until a minimum of the objective function is reached. *GenOpt* has a library of local and global one-dimensional and multi-dimensional algorithms for performing optimization and parametric runs. The platform independence and the general interface make *GenOpt* applicable to a wide range of optimization problems [8]. Coupling of *GenOpt* with a whole building simulation program is shown in Figure 1.

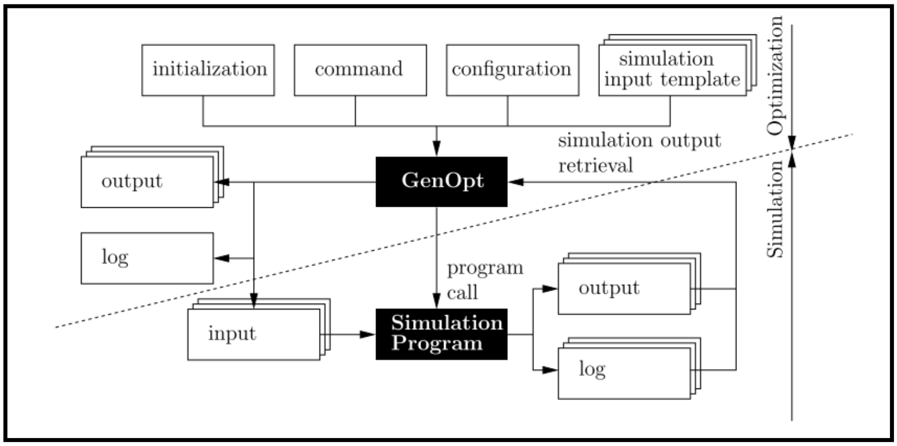

Figure 1: Coupling of GenOpt and a whole building simulation program [8]

Optimization Algorithm:

Selection of the optimization algorithm is one of the key decisions to be made with utmost care. According to literature, it is observed that direct search optimization algorithms, genetic algorithms and hybrid algorithms are the most suited for handling building performance optimization problems [9]. On this basis, the hybrid algorithm - *Generalized Pattern Search Particle Swarm Optimization with Constriction Coefficient Hooke-Jeeves* (*GPSPSOCCHJ*) is applied during the present work. It consists of the *Particle Swarm Optimization with Constriction Coefficient (PSOCC)* algorithm, which is a stochastic population-based algorithm and the *Hooke-Jeeves (HJ)* algorithm, which is a direct search algorithm. This hybrid algorithm initially performs a particle swarm optimization and then switches to the *HJ* algorithm to further refine the results. The main advantage of this algorithm is that the global search of the *PSOCC* algorithm increases the chances of getting close to the global minimum, rather than getting trapped in a local minimum. Subsequently the *HJ* algorithm further refines the search locally.

Optimization Problem Setup:

The three-storey office building under consideration is located at Ratmalana, suburbs of Colombo, having overall dimensions of 8.0 m x 12.0 m x 8.9 m. Computational model of the existing envelope design is shown in Figure 2. Tables 1 and 2 give the details of construction and thermal and electrical loads respectively. Computational model of the office building consists of six equal thermal zones.

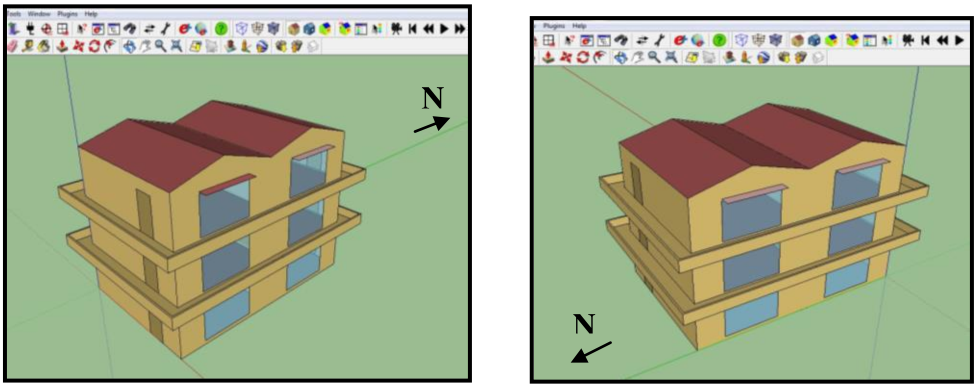

Figure 2: Computational model of the existing envelope design

Table 3 shows the economic data utilized in modelling the Life Cycle Cost of the building. Table 4 gives the range of values of building envelope elements that are used during simulations.

Table 1: Construction Details of the building envelope

Building Element	Construction Details
Walls	225 mm thick brickwork with 15 mm thick cement plaster on both sides.
Roof	Pitched roof of 15^0 with 25 mm thick Calicut tiles.
Floor	10 mm thick ceramic tiles on a 150 mm thick reinforced concrete slab.
Doors	Each of 1.1 m x 2.0 m, made of plywood.
Windows	3.0 m x 2.0 m double pane windows with 4 mm thick glass and 2 mm thick air space. There exists 0.2 m of wall below the window and 0.5 m of wall above the window. The edge of each window is located 1.5 m from the respective wall edge.
Shading overhangs on 3^{rd} floor windows	Depth 0.5 m with 0.1 m height above the window. Tilt angle is 90^0.

Table 2: Thermal and electrical loads per thermal zone of the building

Load / System	Rating and Description
Occupancy	10 nos. of occupants involved in general office work. Thermal load of 130 W/person with specified occupancy schedule.
HVAC system	Temperature control through dual set point, where 20 ^{0}C for heating and 25 ^{0}C for cooling. Maximum indoor air velocity is 0.2 ms^{-1}.
Rated artificial lighting	200 W
Rated electrical equipment	500 W
Building lighting control mechanism	Continuously dims artificial lights to match an illumination set point of 500 lx at the centre of each thermal zone at a working plane of 0.8 m above the floor level, with the variation of day light.

Table 3: Economic data for building Life Cycle Cost

Parameter	Value
Lifetime of the building under study (n)	25 yrs.
Nominal discount rate (D)	10.00 %
Rate of inflation (I)	4.70 %
Real discount rate (d)	5.06 %
Annual rate of escalation in electrical energy price (e)	10.00 %
Current price of electrical energy (E_p)	Rs. 12.50 / kWh
Investment cost on envelope walls	Rs. 4500.00 /m^2
Investment cost on envelope windows	Rs. 1100.00 /m^2
Investment cost on HVAC system	Rs. 80,000.00 per Ton

Table 4: Range of values for building envelope elements

Envelope Element	Type of Variable	Minimum Value	Maximum Value	Existing Design
Building Azimuth Angle (^{0})	Continuous	0	360	0
Window-to-Wall Ratio (WWR) (%)	Continuous	4.0	62.4	29.9
Horizontal position of east windows (m)	Continuous	0.50	2.50	1.50
Horizontal position of west windows (m)	Continuous	0.50	2.50	1.50
Vertical position of east windows (m)	Continuous	0.20	0.80	0.20
Vertical position of west windows (m)	Continuous	0.20	0.80	0.20
Depth of east shading overhangs (m)	Continuous	0.30	1.00	0.50
Depth of west shading overhangs (m)	Continuous	0.30	1.00	0.50

Table 5 shows the settings of the *GPSPSOCCHJ* algorithm during the optimization process.

Table 5: Settings of the GPSPSOCCHJ algorithm

Parameter	Setting
Neighbourhood Topology	Von-Neumann
Neighbourhood Size	1
Number of Particles	16
Number of Generations	20
Seed	0
Cognitive Acceleration	2.8
Social Acceleration	1.3
Maximum Velocity Gain - Continuous	0.5
Maximum Velocity - Discrete	1.0
Constriction Gain	1.0
Mesh Size Divider	2
Initial Mesh Size Exponent	0
Mesh Size Exponent Increment	1
Number of Step Reductions	10

Optimization Results:

The optimization program was run on an Intel Core i5 2.6 GHz workstation of 4.0 GB RAM. It took 1190 Iterations consuming 3 hrs and 17 minutes for the solution to converge are shown in Figure 3.

Table 6 makes a comparison of existing and optimal values of the building envelope elements.

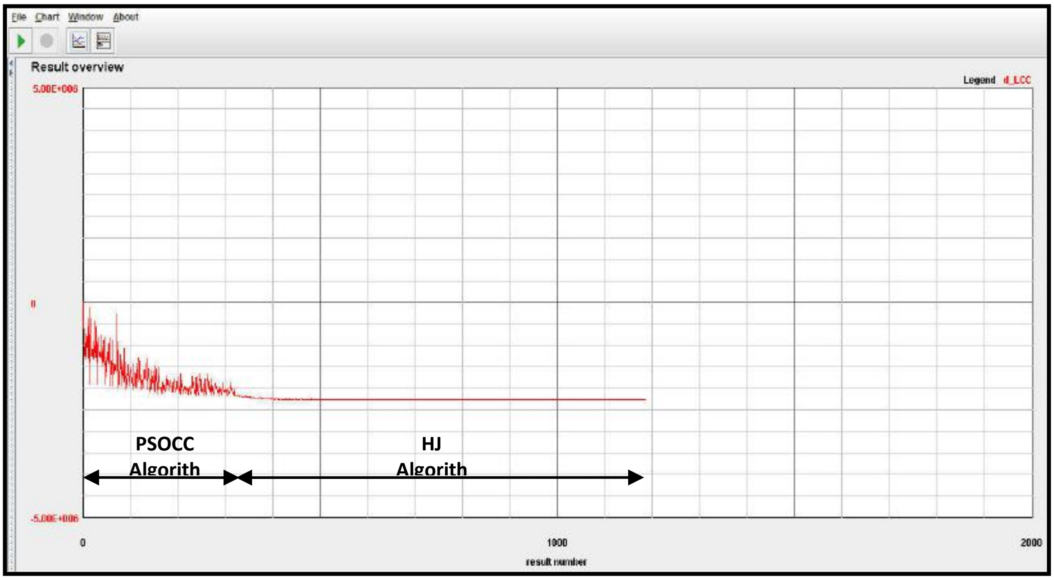

Figure 3: Iterations reaching convergence

Table 6: Comparison of existing and optimum values of envelope elements

Envelope Element	Existing Value	Optimal Value
Building Azimuth Angle (^{0})	0	274
Window-to-Wall Ratio (WWR) (%)	29.9	9.4
Horizontal position of east windows (m)	1.50	2.21
Horizontal position of west windows (m)	1.50	2.36
Vertical position of east windows (m)	0.20	0.80
Vertical position of west windows (m)	0.20	0.80
Depth of east shading overhangs (m)	0.50	1.00
Depth of west shading overhangs (m)	0.50	1.00

Tables 7 and 8 show the saving in annual energy consumption and in the building Life Cycle Cost due to the optimal envelope design.

Table 7: Saving in annual energy consumption

Envelope Design	Annual Energy Consumption [GJ]				$PMV_{weighted}$**
	Q_{heat} x 10^{-3}	Q_{cool}	E_{light}	E_{tot}*	
Existing	5.68	399.81	7.51	541.78	0.75
Optimal	5.33	363.05	9.39	499.68	0.70
Saving (%)	6.2	9.2	-25.0	7.8	-

**Annual primary energy consumption for heating, cooling and lighting*

***Weighted Predicted Mean Vote based on the cooling load in each thermal zone of the office building*

Table 8: Saving in building Life Cycle Cost

Change in Life Cycle Cost (dLCC) (Rs.)	
Investment Cost (dIC)	
dIC_{walls}	203,508.81
$dIC_{windows}$	-49,746.60
dIC_{HVAC}	-34,569.50
ΣdIC	119,192.71
Operational Cost (dOC)	
ΣdOC	-2,385,423.25
dLCC	-2,266,230.54
LCC Saving (%)	7.0

It is evident from Tables 7 and 8 that the optimal envelope design leads to a 7.8% saving in the annual primary energy consumption and 7.0% saving in the life cycle cost of the office building, which can be considered as substantial quantities. Furthermore, the optimal envelope design also leads to a better level of thermal comfort for the occupants of the building. To ensure that the algorithm actually converged to a global minimum, 200 parametric runs based on practical values of possible envelope element combinations were performed. However, none of the parametric runs produced change in building life cycle cost (dLCC) greater than the optimal solution generated by *GenOpt*. Hence, the solution obtained through generic optimization is very likely to be the global minimum of the solution space. Furthermore, it is observed that the reduction in window-to-wall ratio leads to a 25% increase in energy consumption for lighting. However, it is compensated through a substantial energy saving on building cooling, which is the dominant factor, contributing to the saving in annual energy consumption and thereby to the saving in building life cycle cost. Hence, the present work shows that combined performance modelling and generic optimization is an effective methodology that enables the designers to come up with building envelope designs that not only produce optimal life cycle costs, but also lead to better thermal comfort for the occupants.

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Project Management Framework for Active Energy Saving (AES) Projects: Optimizing Life Cycle Energy Cost ofHigh-rise Buildings in Sri Lanka

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Abstract

Energy conservation has become the most pressing concern in the world nowadays. High use of energy and other resources in socio-economic development has been created a necessity to conserve energy through optimum utilization. Buildings are major contributors in such situations where buildings demand energy throughout their life cycle for the construction, operation, rehabilitation and eventually demolition. Worldwide, 30–40% of all primary energy is used for buildings and they are held responsible for 40–50% of greenhouse gas emissions. Hence,building sector has been concentrated on implementing active energy saving mechanisms to reduce energy cost against increasing energy tariff. Further,such energy management projects must have a systematic approach to achieving and maintaining energy savings.Effective project management throughout active energy saving projects is important to introduce so as to optimize life cycle cost of buildings. Therefore, the aim of this research is to develop a project management framework for active energy saving projects. Under the survey approach,a structured questionnaire survey was carried out among a selected sample ofpractitioners in active energy saving projects available in high rise buildings in Sri Lanka. The collected data wereanalyzed by using statistical data analysis techniques. Based on empirical findings, the impact of active energy saving on life cycle cost of high-rise buildings was identified and accordingly, a project management framework was developed for active energy saving projects to optimize energy savings and life cycle cost of high-rise buildings in Sri Lanka.

Key words: Active energy saving, Life cycle Cost, High-rise buildings, Project management

Introduction

Due to economic and environmental reasons, organizations around the world are constantly under pressure to reduce energy consumption. As energy cost is one of the main cost drivers for businesses, reduction in energy consumption leads to reduction in operating costs, and thereby helps to improve the profitability of organizations [7].Buildings demand energy throughout their life cycle from the construction to demolition[9]. As indicated by [8], operating (80%–90%) and embodied (10%–20%) phases of energy use are significant contributors to a building's life cycle energy demand and life cycle energy requirement of office buildings falls in the range of 250–550 kWh/m^2/year. As they further verify, operational energy has a great influence on life cycle energy demand of buildings [8]. According to [2], in a study of 60 commercial buildings in United States of America, it has been found that 25% had problems with the energy management system and variable speed drives (VSD) and these underperforming systems impact the operation of buildings negatively and may lead to excessive energy use, high maintenance costs and low occupant satisfaction.A building's life cycle energy demand can be reduced by minimizing its operating energy significantly through the use of active energy saving (AES) technologies [8]. Life cycle energy analysis assumes greater influence for formulating such strategies to achieve reduction in primary energy use of the building and to control emissions. Further, the effective planning and management of AES projects with sound investment evaluation help to achieve projected energy and cost savings throughout the whole life cycle of buildings. Therefore, the aim of this research is to develop a project management framework for AES projects in order to optimize the life cycle cost of high-rise buildings in Sri Lanka. The ultimate aim is achieved by three objectives as follows;

Identifying active energy saving mechanisms

i. Evaluating impact of active energy saving on life cycle cost of buildings
ii. Investigating project management criteriafor optimizing energy and cost savings through AES projects

The next section describes the secondary data on whole life energy use, operational energy consumption, active energy saving and necessity of project management for best practice.

Literature Review

Whole life energy use in high-rise buildings

Buildings are constructed for residential, office and commercial purposes all over the world. They are major contributors to socio-economic development of a nation and also utilize a large proportion of energy and available natural resources. Buildings consume energy directly or indirectly in such all phases of their life cycle. Life cycle energy analysis of buildings assumes great significance for formulating strategies to achieve reduction in primary energy use of the buildings and control emissions. Life cycle energy of a building is the sum of all the energies incurred in its life cycle, namely embodied energy, operating energy and demolition energy [8]. Embodied energy is the energy utilized during the manufacturing phase of buildings. It is the energy content of all the materials used in buildings and energy incurred at the time of construction and renovation. Operating energy is used for maintaining comfort conditions and day-to-day maintenance of buildings whilst the demolition energy is required at the end of service life of the building for demolishing and transporting building waste to landfills. As this study [3] highlighted that in the building sector, a life cycle approach is an appropriate method for analysis of energy and use of other natural resources as well as the impact on the environment.

Among the other phases, operating energy creates huge impact on whole life cost of buildings. Twenty seven cases from literature stated in [11] and [5] depict that the relationship between operating energy and life cycle energy of buildings is almost linear despite climatic and other differences as shown in Figure 2.1. Case studies of the total energy use reported that 85% of the total energy usage was required during the operation phase and energy used in manufacturing all the construction materials employed in construction with the erection and renovation amounts approximately to 15% of the total energy use. According to the study by [7], 64% of the total energy consumption accounts for heating, ventilation and air conditioning (HVAC) system whilst lighting accounts for 10% and miscellaneous loads account for 26% of the total energy consumption.

Active energy saving and its impact on life cycle energy

The reduction in energy consumption can be achieved through energy efficiency and energy conservation programs. In a case study carried out in the period 1995-2003 for a large office building in Colorado by [10], energy efficiency improvement projects resulted in verified savings of 14%in electrical demand, 25% in electrical use and 74% in gas use. Field results have shown that proper projects can yield cost-effective savings between 5-20% with a typical payback of two years or less as per [12].

Several case study results show that life cycle energy savings are in accordance with reduction in operating energy which in turn is proportional to the degree and number of passive and active energy saving measures used in the building. The previous studies conducted by [1], [13] and [4] have been found energy saving measures such as mechanical ventilation with plate heat exchanger, solar collectors, increased insulation on façade, photo voltaic system, air heat recovery, etc. Those studies further showed that life cycle energy savings are in accordance with reduction in operating energy which in turn is proportional to the degree and number of energy saving measures used in the building.

Table1: Energy saving measures in buildings

	Energy saving measures	Reduction in operating energy (%)	Life cycle energy saving (%)
1	Mechanical ventilation with plate heat exchanger	15	14
2	Solar collectors	30	26
3	Increased insulation on façade	20	16
4	Photo voltaic system and air heat recovery	62	50

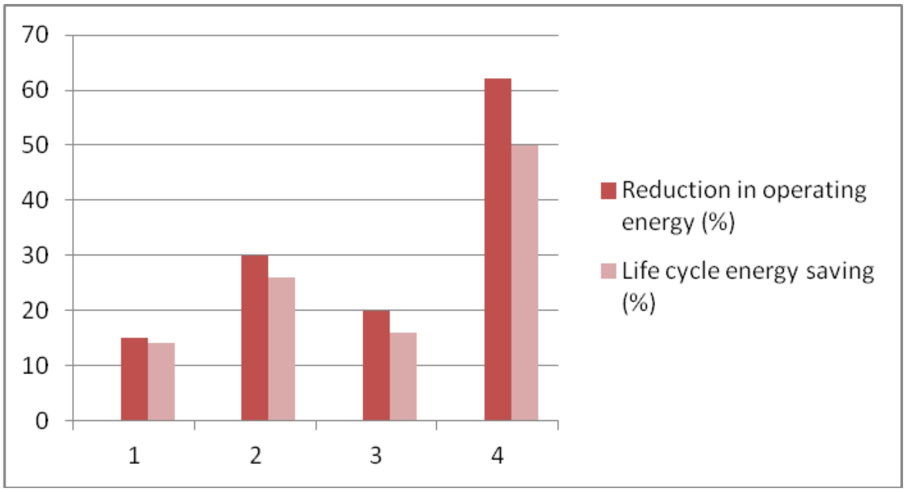

Figure2: Operating energy reduction and life cycle energy savings (Jayamaha, 2006)

The above Figure 2.3 shows the relationship between operating energy reduction of some passive and active energy saving mechanisms and their impacts on life cycle energy saving in a building. Among the other mechanisms, variable speed drive (VSD), energy efficient lighting, power factor improvement, etc. can be identified as major active energy saving mechanisms which have great influence on life cycle energy reduction[7].

Necessity of project management for active energy saving

Energy management requires a systematic approach to achieving and maintaining energy savings. The successful completion of a project is usually the product of joint planning, continual review and flexible contracts and especially the cooperation. There are some common factors despite the disarray created by the variety of project situations. The overall pattern is the same in most cases; a sequence of phases is followed, from planning through design, procurement and installation to commissioning [6].

Planning and design phase

The outcome of this phase should be the selection of a defined project which meets the stated project objectives, together with a broad plan of implementation. An effective feasibility study should use consistent methods and levels of detail in preliminary design and estimates of costs and benefits over all options [6].

Procurement and installation phase

During this phase, procurement strategy should be refined and a detailed procurement plan should be established. The term ‘procurement’ relates to all the goods and services required for the project, and it includes consideration of the installation contracts as well as the supply of equipment and materials to be installed

Monitoring and controlling phase

Project evaluation is one of the tasks of project management during each phase and when approaching points of decision, approval or change. As part of this evaluation, the project manager must be able to review a set of project data and extract the salient facts.

Closing/Commissioning phase

Commissioning is the orderly sequence of testing, adjustment and bringing into operation of those subunits and units of the project, after the construction and installation work is finished.

Research Methodology

A comprehensive literature review was carried out in order to identify the research problem. In this research, survey method was identified as the most appropriate approach and questionnaire surveys have been conducted. The energy demand indicators and energy performance of high-rise office buildings in Sri Lanka were analyzed according to the research objectives.Further, financial analysis was conducted on real-time AES projects that have been implemented in middle and high rise office buildings in Sri Lanka. Further, an in-depth literature review and a preliminary survey were conducted to identify the project management phases and sub criteria regarding AES projects and the other questionnaire survey was based on them. Opinions about project management were obtained from the questionnaire survey from practitioners such as facilities managers, premises managers, maintenance managers and engineers of middle and high rise office buildings in Sri Lanka. The project management phases and sub criteria of AES projects were prioritized by analytical hierarchy process (AHP) tool.

Research Findings and Discussion

Energy demand in high-rise buildings in Sri Lanka

Fourteen middle and high rise office buildings in Sri Lanka were selected to conduct the operational energy analysis and to predict whole life energy demand. Literature proves that the operational energy demand is 80% of the life cycle energy demand [8]. Thus, the life cycle energy demand of high-rise office buildings in Sri Lanka is predicted as shown in Table 2.

Table2: Energy demand of high and middle rise office buildings in Sri Lanka

Building	Year of handover	Gross floor area (m^2)	Life span (years)	Monthly average maximum demand (kVA)	Operational energy demand ($kWh/m^2/year$)	Life cycle energy demand ($kWh/m^2/year$)
I	1997	18,087	50	695	137.24	171.55
B	2003	41,806	100	1,696	165.06	206.33
E	2008	15,860	50	824	166.69	208.36
H	1998	18,581	50	1,029	168.73	210.91
A	1997	117,100	99	4,908	171.10	213.88
M	1984	56,067	100	1,632	171.37	214.21
L	1997	18,116	100	746	193.28	241.59
J	2001	14,370	50	620	193.38	241.73
G	1992	23,568	50	953	210.85	263.57
N	1998	23,600	100	1,072	242.32	302.90
D	2008	2,911	40	160	249.91	312.39
K	1998	3,735	50	252	260.56	325.70
F	1998	6,968	40	534	295.77	369.71
C	2005	3,063	40	362	355.07	443.83

The predicted energy demand in above Table is graphically illustrated in following Figure3.

Figure3: Operational energy demand of high rise office buildings in Sri Lanka

Financial analysis of AES projects in Sri Lanka

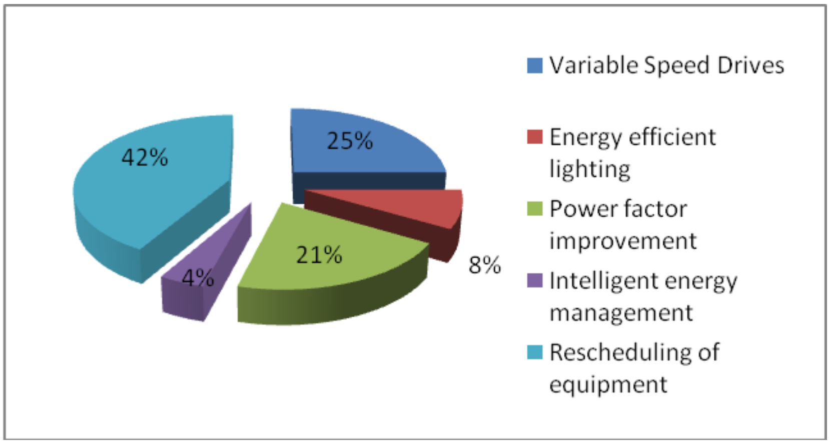

Figure4: Amount of each AES project category in the sample

Among the other energy saving mechanisms, five active mechanisms were selected to conduct the financial analysis which are implemented in high-rise buildings in Sri Lanka such as, Variable speed drives (VSD), energy efficient lighting, power factor improvement, intelligent energy management, rescheduling of equipment. Twenty four real-time AES projects that have been implemented in high rise buildings were selected to analyze the impact of AES projects on whole life cost of those buildings. The amount of AES projects in each category of the sample for this research is mentioned in above Figure 4.

The average values of each category of AES projects were obtained to arrive with following results of financial analysis relating to the life cycle cost of the projects.

Table 3: Project details of AES projects

Project	Initial investment (LKR)	Life time (years)	Annual energy saving (kWh)
Variable speed drives (VSD)	955,750	10	85,024
Energy efficient lighting	900,000	6	46,200
Power factor improvement	497,169	5	814
Intelligent energy management	25,868,500	20	1,143,756
Rescheduling of equipment	-	10	190,957
Average	**5,644,284**	**10**	**293,350**

Energy savings by rescheduling of equipment

The following Table 4and Table 5 show the project details relating to the selected AES projects in high-rise buildings in Sri Lanka with the initial cost and annual energy savings. Table 4 shows the project details and related energy savings of rescheduling of equipment whilst Table 5 illustrates the project details of variable speed drives projects, energy efficient lighting projects, power factor improvement projects and intelligent energy management projects.

Table4: Rescheduling of equipment

Project code	Project start (year)	Initial investment (LKR)	Lifetime (years)	Annual energy saving (kWh)
A-4	2008	-	10	31,680
A-5	2008	-	10	176,640
A-9	2007	-	10	192,182
A-10	2007	-	10	584,800
A-11	2007	-	10	87,904
A-12	2007	-	10	314,794
A-13	2008	-	10	221,076
A-14	2009	-	10	47,916
A-15	2008	-	10	125,424
A-16	2007	-	10	127,152
Average			**10**	**190,957**

Table5: Other AES projects

Project code	Project start (year)	Initial investment (LKR)	Lifetime (years)	Annual energy saving (kWh)
VSD projects				
A-1	2009	1,100,000	10	180,000
A-2	2009	1,100,000	10	144,000
A-8	2009	434,500	10	72,144
B-1	2006	1,000,000	10	48,000
M-1	2010	1,500,000	10	36,000
M-4	2009	600,000	10	30,000
Average		**955,750**	**10**	**85,024**
Energy efficient lighting projects				
A-3	2009	600,000	6	57,600
M-2	2010	1,200,000	5	34,800
Average		**900,000**	**6**	**46,200**
Power factor improvement projects				
A-6	2008	183,750	5	600
A-7	2007	928,500	5	2,050
C-1	2010	647,870	6	516
F-1	2010	468,742	5	411
I-1	2009	256,984	5	492
Average		**497,169**	**5**	**814**
Intelligent energy management projects				
G-1	2006	25,868,500	20	1,143,756

By implementing such active energy saving mechanisms, high-rise buildings can achieve energy savings by reducing the operating energy cost of buildings.

The following Table 6 shows the financial evaluation above selected AES projects on life cycle cost of buildings.

Table6: Financial evaluation of AES projects

Project	NPV (Rs.)	IRR	Adjusted ROI
Variable speed drives (VSD)	11,522,772	149%	1184%
Energy efficient lighting	3,262,112	99%	431%
Power factor improvement	2,307,725	123%	464%
Intelligent energy management	262,754,805	59%	784%
Rescheduling of equipment	28,636,051	-	-
Average	**61,696,693**	**107%**	**716%**

Such energy saving and cost reductions can be achieved by successful planning and management of AES projects thus, the following section describe the importance of project management for AES projects.

Importance of Project Management for AES Projects

The opinions collected from the practitioners of high-rise office buildings were prioritized by using AHP tool. Importance scores were obtained for main phases of AES project management and sub-criteria as mentioned in Following Table 7.

Table 7: Importance scores for main phases

Criterion	Importance score	%
Planning and design phase	0.541	54
Procurement and installation phase	0.238	24
Monitoring and controlling phase	0.132	13
Closing/commissioning phase	0.088	9

According to Table 7, the highest importance score has been secured by planning and design phase with an importance score of 0.541. In other words practitioners have ranked planning and design phase as the most important AES project management phase.

Sub criteria

Table8: Importance scores for sub criterions

Sub criterion	Importance score	%	Final importance score	Final %
Planning and design phase				
Cooperation of the director board/management	0.205	21	0.111	11
Realistic project schedule/duration	0.157	16	0.085	8
Realistic budget	0.187	19	0.101	10
Financial evaluation criteria	0.165	16	0.089	9
Risk assessment	0.124	12	0.067	7
Competency of the outsourced consultant	0.075	7	0.040	4
Sufficient resource allocation	0.088	9	0.048	5
Procurement and installation phase				
Tender selection method	0.191	19	0.045	5

Availability of speedy funds	0.163	16	0.039	4
Competency of the in-house project team	0.128	13	0.031	3
Competency of the contractor	0.188	19	0.045	4
Quality of equipment supplied	0.242	24	0.058	6
Support of the in-house facilities/maintenance staff	0.089	9	0.021	2
Monitoring and controlling phase				
Measuring the ongoing project activities	0.128	13	0.017	2
Monitoring the project variables (cost, time, scope, etc.)	0.185	18	0.024	2
Identify corrective actions to address issues and risks	0.199	20	0.026	3
Frequent project meetings	0.085	8	0.011	1
Managing planned project schedule	0.132	13	0.017	2
Managing planned budget	0.127	13	0.017	2
Continuous quality assurance	0.145	15	0.019	2
Closing/commissioning phase				
Commissioning schedule	0.263	26	0.023	2
Commissioning programme	0.231	23	0.020	2
Training for in-house staff	0.273	27	0.024	2
Documentation	0.233	23	0.021	2

Table8 demonstrates the importance scores which have been secured by each sub criterioncoming under project management of an AES project.

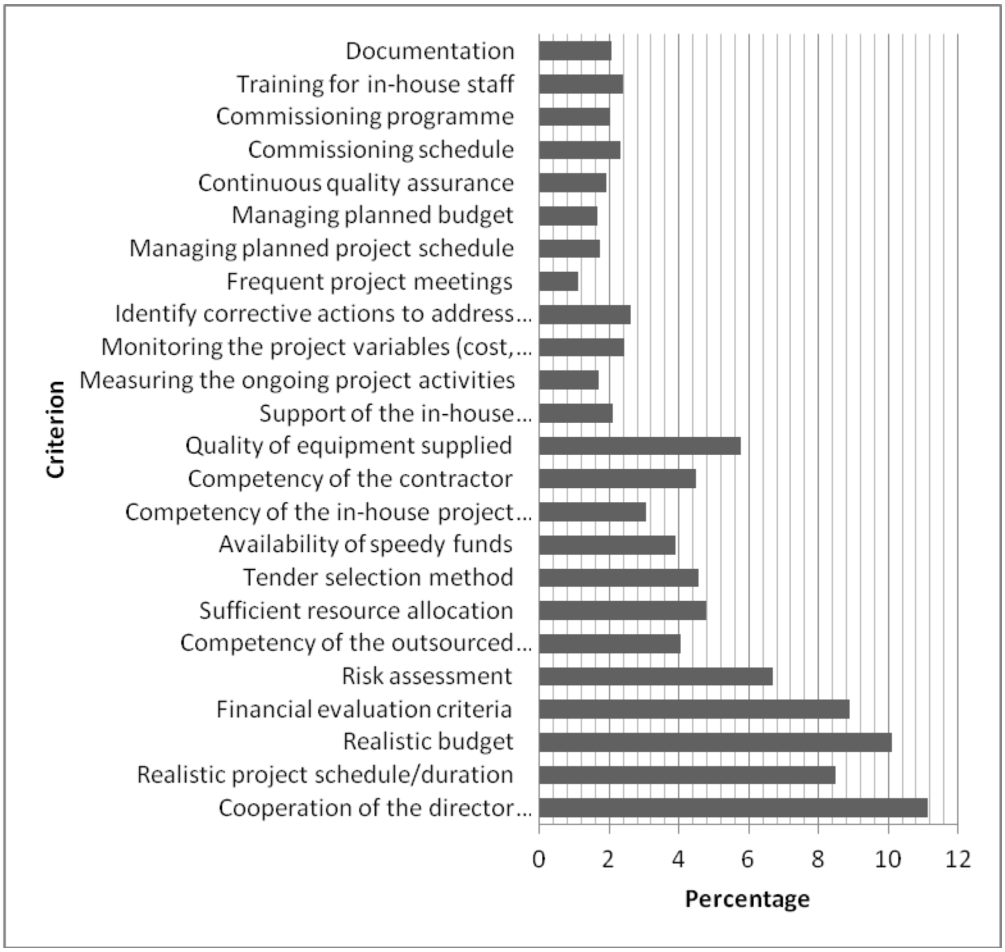

Figure 5: AES project management framework

All the sub-criteria have been shown in above Figure 5 with their respective final importance levels in an overall perspective. Practitioners have ranked cooperation of the director board as the most decisive criterion which can affect the final outcome of an AES project with an importance level of 11%. Forecasting a realistic budget at the planning and design phase has also been ranked at a higher level with an importance level of 10%. Further, importance of financial evaluation criteria, forecasting of a realistic project schedule, risk assessment and quality of equipment supplied for the AES project have been recognized significantly.

Conclusions

Energy conservation has become the most pressing concern in the world nowadays. Due to economic and environmental reasons, organizations around the world are constantly under pressure to reduce energy consumption. Buildings consume energy directly or indirectly in all phases of their life cycle in the ways of embodied energy, operating energy and demolition energy.

Among the other phases, operating phase is important to be considered as it consumes more energy, however, several active and passive energy saving measures can be implemented during that stage to reduce energy usage and thus, life cycle energy and cost. Active energy mechanisms such as rescheduling of equipment, energy efficient lighting, power factor improvements and intelligent energy management projects in high-rise buildings in Sri Lanka were evaluated to identify their impact on life cycle energy, energy saving and financial return throughout the life cycle of the building. Such energy savings and cost reductions can be achieved through successful project management. Therefore, the latter part of this research was intended to identify the importance of project management for AES projects by developing a best practice framework considering all the project phases. Among the other phases, Planning and design phase has been recognized as the most important phase of an AES project with an overall importance level of 54%. Procurement and installation phase was also ranked high with an overall importance level of 24%.Sub-criteria such as cooperation of the director board, forecasting a realistic budget, financial evaluation criteria, forecasting a realistic project schedule, risk assessment and quality of equipment supplied for the project were ranked highly important with an overall importance level above 6%toward success of AES projects. The developed framework to anticipate the annual energy consumption (kWh/year) and monthly average maximum demand (kVA/month) of middle and high rise office buildings can be utilized by architects, quantity surveyors, engineers and facilities managers to predict the energy demand even at the design phase of a future development. Ultimately the developed best practice framework for successful project management in AES projects would assist the practitioners to prioritize their decisions in project management which in turn would optimize the monetary outcome through enhanced savings.

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A Methodological Framework to Rank Energy Efficient Cities using Walkability Measures

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Abstract

Energy efficiency may be the cheapest, most abundant, and most underutilized resource for local economic and community development.In today's context motorized transportation is highly being used, which results in more energy waste and pollution. Walking receives a considerable interest asa non-polluting transportation mode which results in energy saving as opposed to motorized traffic. We can have more energy saving cities by reducing the motor traffic and promoting more pedestrian friendly cities. In this context, measure of "walkability" has been used to evaluate the pedestrian facilities. The present work attempts to identify a ranking system of cities to rank them in their energy efficiency in terms of walkability with the identified indicators.These indicators included daily traffic counts, pedestrian counts and an evaluation of existing road links with the available pedestrian facilities within the city center. On the basis of the surveys performed, the significance of indicators was determined.Since this is an initial attempt in ranking energy efficient cities in terms of walkability, researches can further develop this methodological frameworkand fine-tune it towards an all-inclusive ranking system of energy efficient cities.

Key Words: Motorized transportation, Walking, Pedestrian

Introduction

Energy efficiency may be the cheapest, most abundant, and most underutilized resource for local economic and community development.Generally, energy efficiency is using less energy in providing the same service.Efficient energy use, sometimes simply called energy efficiency, is the goal to reduce the amount of energy required to provide products and services. There are many motivations to improve energy efficiency such as reducing energy use. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases.According to[3], of the €200 billion spent globally on clean energyin 2011, less than 7% went to energy efficiency.Energy efficiency and renewable energy are said to be the twin pillars of sustainable energy policy and are high priorities in the sustainable energy hierarchy. In many countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted.

Cities are an important engine for economic growth and socio-economic development. Rapid urbanization in recent decades has led to ever-expanding cities, creating massive requirements for energy to fuel growth and expand basic service infrastructure. This demand for energy has enormous implications for cities, particularly their operating budgets, competitiveness, service quality and cost, quality of life and local and global environmental impacts. Energy is widely viewed as the lifeblood of cities, powering public services, hospitals and schools while moving people within the city and beyond. Reducing energy use through energy efficiency measures and planning can lower a city's dependence on imported fuels and its energy costs while freeing up resources that can improve or extend city services. Improving a city's design and planning functions can have dramatic implications on future energy needs.

Further, cities are key players in the reduction of CO_2 emissions and the fight against climate change. Energy consumption in urban areas – mostly in transport and housing – is responsible for the largest share of CO_2 emissions.Cities can lead in the reduction of CO_2 emissions and the fight against climate change. Walking receives a considerable interest asa non-polluting transportation mode which results in energy saving as opposed to motorized traffic. We can have more energy saving cities by reducing the motor traffic and promoting more pedestrian friendly cities.Researches carried out in order to promote walking come to the general conclusion that favourable walking environment is an essential pre-condition to promote pedestrian trips. Measure of "walkability" has been used to evaluate the pedestrian facilities. The objective of this research is to propose a methodology that would enable to rank cities according to their energy efficiency in terms of walkability.

Walkability

Walking is beneficial to people's health, to community vitality, and for the environment. According to a report prepared by the Maine Development Foundation, "walking improves community interaction as people are more likely to talk with neighbors and shop in local stores when they are walking through a community. It also provides easy, inexpensive and low-impact exercise that can improve the overall health of community residents. Walking instead of driving also protects environmental quality. Reducing vehicular emissions benefits plants, watersheds and the health of wildlife and people alike Utility-related walking includes household, transportation, or occupation purpose walking and that has now become a solution in sustainable transport systems. Presence of facilities for pedestrians is at vital importance in both utility-related walking and recreational walking.

Walkability is an idea of quantifying the safety and desirability of walking routes. It is simply the overall support for pedestrian travel in an area or in other words, the extent to which the built environment is friendly to the presence of people living, shopping, visiting, enjoying or spending time in an area. Walkability does not have a clear cut definition and it often differs according to the context. According to Mackmillan Dictionary walkability is a measure of how easy it is to walk around in an area easily and safely. Some urban planners tend to think of walkability in terms of a city's spatial land use arrangement, favoring mixed-use zoning over segregated uses. In the Walkability Index project, walkability is considered in its most basic sense: the safety, security, economy and convenience of traveling by foot. As per the Healthier worksite Initiative, walkability is a measurement of the transportation and recreation opportunities for pedestrians, and considers pedestrian safety, convenience and route aesthetics.[5] Considered Walkability as a measure of the urban form and the quality and availability of pedestrian infrastructure within a defined area. According to [7], Walkability is a measure of the extent to which the public realm provides for movement and other activities on foot, in ways that are both efficient and enjoyable.

At present walkability is evaluated using qualitative measures that are very subjective. The factors affecting walkability were subjected to debate among so many researchers. Some cities have undertaken comprehensive studies and city plans to improve walkability[7] defines walkability as "the extent to which walking is readily available to the consumer as a safe, connected, accessible and pleasant activity." For New Zealand, it was defined as the extent to which the built environment is walking-friendly (New Zealand Transport Authority 2007). As it was discovered by

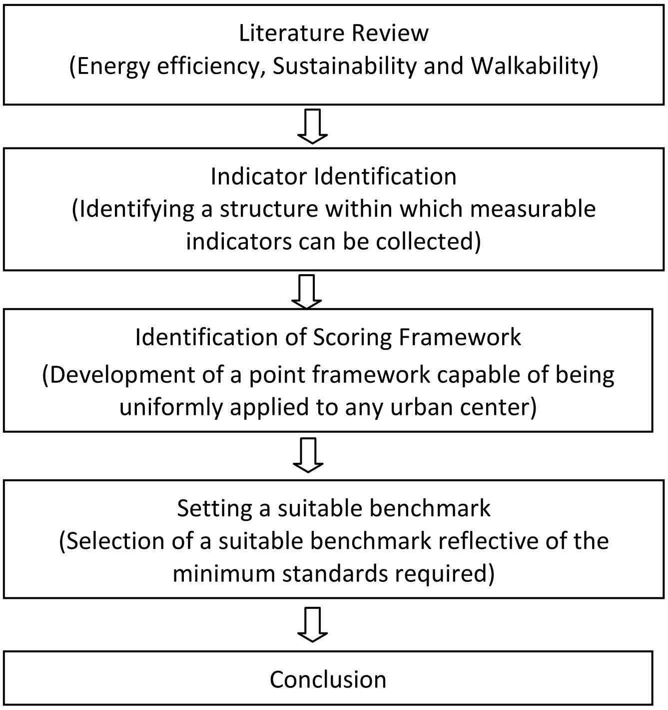
Walkscore (www.walkscore.com), improving walkability will provide economics saving and benefits which has resulted in the increase of housing prices. Hence improving walkability has many economic benefits. It was found out that walking communities have social benefits as well. Walkable communities are climate-friendly; they promote safety and walking makes a healthy community.

"In practice and in research, the term walkability appears in relation to a variety of settings displaying a range of features. A clear understanding of what walkability is and what elements define its form and function would enhance the practical value of the concept"[6]. From the walking behaviour literature Shay et al found that following factors are affecting walkability.

1. Accessibility, convenience (proximity to destinations within walking distance)
2. Mixed land use
3. Density (employment or residential)
4. Pedestrian facilities (sidewalks, crosswalks, walking trails)
5. Aesthetics (friendly feel, attractive architecture, landscaping, street trees)
6. High connectivity (access to destinations, intersections, block length)
7. Low traffic volume and speed
8. Company (walking with another individual)
9. Access to public open space
10. Access to transit
11. Other (freedom from obstacles, crime safety, access for special populations)

Methodology

Given that this paper is primarily going to rank energy efficiency of cities the selection of area specific indicators and the derivation of an appropriate points scoring frame work, it is necessary to set this within the context of the wider research methodology as indicated in Figure 1.



Indicator Selection Process

Indicator selection is of particular importance with the selection process depending on the nature of the research being carried out. According to the Expert Group on the Urban Environment (European Commission DGXI, 1996), the development and selection of indicators is a long and complex process. The selection of some indicators may be obvious while either it is not clear which indicators are the most appropriate or the data to evaluate the preferred indicators are not available. The first and most important step in the process of developing indicators is to clarify the basic concept to be represented in the analysis [1].

Since the energy efficiency is measured only using walkability measures it is imperative to have a comprehensive understanding of walkability and its measures. Hence the selection of indicators has to be rigorously assessed, with the value and practicalities of each potential indicator appraised in terms of the following considerations: data availability, geographical specification, time-series prospects, implementation and interpretability. In this paper, the selection of most appropriate indicators is done in five major groups that is pedestrian infrastructure, physical properties of sidewalks, connectivity and convenience, pedestrian safety andbuildings and land use.

Pedestrian infrastructure reflects the characteristics pedestrian facilitiesexcept sidewalks and amenitiesin urban centers. This evaluates the existing pedestrian facilities of the particular urban center.The second group of indicators is categorized as physical properties of sidewalks which incorporate presence and condition of sidewalks. Connectivity and convenience group encompasses the connectivity of urban area which makes it convenient for pedestrians.Pedestrian safety reflects howsafethe urban center is for pedestrians.The last indicator, which is buildings and land use represents the liveliness of the urban center. This livability makes pedestrian friendly environment for the people to walk comfortably in the urban center. The indicators of these groups are presented in Table 1.

Table 1:Indicator description

Group	Indicator description
Pedestrian Infrastructure	• Location of bus stops • Pedestrian amenities and disability facilities • Availability of cross walks
Physical Properties of sidewalks	• Presence and continuity of sidewalks • Effective width and elevation • Obstructions
Connectivity and convenience	• Accessibility to destinations • Connectivity routes and networks
Pedestrian Safety	• Street lighting • Vehicle volume and speed • Pedestrian accidents
Buildings and Land use	• Land use mix • Residential use • Retail use

For the assessing of most of these indicators the score card developed by [2] was used. For the location of bus stops the distance of the bus stops located on urban road network was used. Priorities for pedestrians, cyclists and public transport was considered under pedestrian amenities along with the amenity measures developed in the score card developed by [2] as shown in Table2.

Table 2: Pedestrian amenities evaluation

Pedestrian amenities		
Benches/ seating facility	YES	NO
Bus halts with seats	YES	NO
Bus halts with shelter	YES	NO
Information boards/ Road maps	YES	NO
Properly placed Bollards	YES	NO
Public toilets	YES	NO
Sufficient shade	YES	NO
Sufficient lighting	YES	NO
Trees	YES	NO
Drinking water facilities	YES	NO

Score =x ⁄ 10 x100%
Where, x= Number of "Yes" entries
The number of one facility or the frequency of such is not evaluated.

For disability facilities, the score card measures were used. Table 3 represents the assessing of disability facilities indicator.

Table 3: Disability facilities evaluation

3	Disability Infrastructure		
i	Correctly placed tactile paving along the sidewalks	YES	NO
ii	Correctly placed tactile paving along the crossings	YES	NO
iii	Gradient/ slope of sidewalks are convenient (less then 1:20)	YES	NO
iv	Cross slopes are convenient (less than 1:50)	YES	NO
v	Dropped curbs/ curb ramps are present at road junctions where there is a change in level	YES	NO
vi	Water does not pool on pathways	YES	NO
vii	No open drains/ tree routes across pathways	YES	NO
viii	Central ramps with flared sides	YES	NO
ix	Ramp surface is wider than 900mm	YES	NO
x	Ramps have non-slip surfacing	YES	NO
xi	Color of ramps and flare sides are contrast with surrounding	YES	NO
xii	Curb ramps leaves at least 900mm of the pathway and do not obstruct through flow	YES	NO
xiii	No overhead obstructions below 2200 mm	YES	NO
xiv	Audible warnings at pedestrian crossings	YES	NO

Score = $(x/14) \times 100\%$, Where, x = Number of "Yes" entries

Pedestrians seek frequent crossing points. [3]reported that most people will walk 150 feet (46 m) to get to locations rewarding their arrival. The best shopping districts arrange crossings in each 300 - 400 feet (91 ~ 122 m). According to [4], when there are no opportunities provided for crossing streets, pedestrians tend to jaywalk, increasing their risk of injury or harm. Ideally, crossing opportunities, when in the form of pedestrian bridges or subways (less desirable for elderly and the disabled), signalized crossing, or other form, there should be crossings at least every 300 meters to be considered acceptable [4].For availability of cross walks indicator the proposed survey form was used in[2].

Sidewalks are widely considered as the backbone of pedestrian transportation network. A sidewalk can be defined as the portion of a highway, road or street intended for the use of the pedestrians. This can also be called pathways or trails, but pathways and trails do not have clearly defined area or right of way for pedestrians. When evaluating physical properties of sidewalks three indicators were used as presence and continuity of sidewalks, effective width and elevation and obstructions. Here again the scorecard was used which developed by [2].

For buildings and land use group, the measurements used are land use entropy score, net dwelling density and net retail area.

Land use entropy score

$$\text{Land use entropy score} = \frac{\sum_k (P_k \ln p_k)}{\ln N}$$

Net dwelling density

$$\text{NDD} = \frac{\text{No. of dwelling units}}{\text{Total residential land area}}$$

For connectivity and convenience measures intersection density index and Link-Node Ratio was used.

Link node ratio =- number of links / number of nodes

Intersection density Index

$$\frac{\text{Number of intersections}}{\text{Road area}}$$

Under the pedestrian safety group measurements are availability of street lights and length between them, permitted vehicle speeds at the urban center and pedestrian accidents. For modal conflict measure the scorecard was adopted from [2]. There Modal conflict is measured under three sub topics. When there is a buffer, the conflict with pedestrians and motorists would not occur. The requirement of a buffer may depend on so many factors such as; traffic flow in the adjacent lane, sidewalk width and curb elevation. Elevated sidewalks also help to reduce the modal conflict. If a road can score well in either way, it is sufficient for the convenience of pedestrians.

Allocation of Points within the Scoring Framework

The application of indicators has little or no meaning unless set against a scoring system. This way any urban center can be evaluated in term of its performance against a benchmark establishing through the weighting and scoring of indicators. In order to assess the energy efficiency of the urban centers, it is necessary to make comparisons against some established criteria that can denote an acceptable level.

A scale of 0 to 10 was used, where 0 represented no contribution to energy efficiency and 10 represented the maximum or optimum level of contribution to energy efficiency.For each individual indicator, it was necessary to establish a framework of points which in principle could be uniformly applied across urban centers, to ensure that the allocation of points to any urban center was administered from the same perspective thereby facilitating comparison of different urban areas. The point scoring system for the identified groups that is pedestrian infrastructure, physical properties of sidewalks, connectivity and convenience, pedestrian safety and buildings and land use are shown inTables4,5,6,7 and 8.

Table 4: Point scoring system for the pedestrian infrastructure group

Indicator description	Points scoring frame work
Bus stops per 1km length road	0 = 0 points 1-3 = 2points 3-5 = 4 points 6-8 = 6 points 9-10 = 8 points >10 = 10 points
Pedestrian amenities	0-10% = 0 points 10-20% = 2 points 30-40 % = 4 points 50-60% = 6 points 70-80% = 8 points 90-100% = 10 points
Disability facilities	0-10% = 0 points 10-20% = 2 points 30-40 % = 4 points 50-60% = 6 points 70-80% = 8 points 90-100% = 10 points
Distance between cross walks	>1000m = 0 points 800-1000m = 2 points 600-800m = 4 points 400-600m = 6 points 200-400m = 8 points 0-200m = 10 points

Table 5: Point scoring system for the physical properties of sidewalks indicators

Indicator description	Points scoring frame work
Effectivewidth of sidewalks	0 = 0 points 0-1m = 2points 1-2m = 4 points 2-3m = 6 points 3-4 m = 8 points >4m = 10 points
Presence and length of sidewalks per road	0= 0 points 0-1km = 2 points 1-2.5km = 4 points 2.5-5km = 6 points 5-7.5 km = 8 points >7.5km = 10 points
Surface condition of Sidewalks	no= 0 points Not paved = 2 points paved and damaged = 4 points uniformly paved = 6 points firm and stable surface= 8 points Tactile paved = 10 points

In order to establish the comparisons of different urban centers and to rank those urban centers, it is necessary to set a suitable benchmark reflective of the minimum standards required to confirm any urban center as energy efficient urban center. In terms of this research, the issue of setting a benchmark or a threshold is based upon the scoring and weighting system. Each individual indicator is capable of scoring a maximum of 10 points. The summation of these for each indicator set is multiplied by the appropriate weighting for the particular indicator group (Table 9). In turn the total for each indicator group are combined to create a grand total, representative of the contribution of a particular urban center towards energy efficiency. This overall summation is the point's total that can be used when ranking energy efficient urban centers. In order to determine the threshold, where an urban center is not energy efficient, the selected technique involved the tabulation of the total weighted points possible with the threshold set as a percentage on a sliding scale ranging from poor to excellent (Table 10& Table 11).

Table 6: Point scoring system for connectivity and convenience

Indicator description	Points scoring frame work
Intersection density index	0 = 0 points 0.1-0.2 = 2points 0.3-0.4 = 4 points 0.4-06 = 6 points 0.6-0.9 = 8 points 1 = 10 points
Link node ratio	0= 0 points 1-2 = 2points 3-4 = 4points 5-6 = 6points 7-8 = 8points >9 = 10points

Table 7: Point scoring system for the Pedestrian safety indicators

Indicator description	Points scoring frame work
Number of light poles per 1km of road	0= 0 points 1-2 = 2points 3-4 = 4points 5-6 = 6points 7-8 = 8points >9 = 10points
Pedestrian accidents per year	0= 10 points 1 = 8 points 2= 6points 3= 4 points 4 = 2point >5 = 0 points

Table 8: Point scoring system for theLand use and buildings indicators

Indicator description	Points scoring frame work
Land use entropy score	0 = 0 points 0.1-0.2 = 2points 0.3-0.4 = 4 points 0.4-06 = 6 points 0.6-0.9 = 8 points 1 = 10 points
Net dwelling density	<50 per km^2= 0 points 51-100 per km^2= 2 points 101-150 per km^2= 4 points 151-200 per km^2= 6 points 201- 250per km^2= 8 points >250 per km^2= 10 points

In the weighting of the indicator set, it is very important that the weighting must reflect the relative contribution of each factor. The factors were weighted with the consultation of professionals and graduate students of multi-disciplinary areas. This involves a scoring of the indicators of the major five groups in terms of their relative importance in contribution to walkability. These scores were transferred by multi-criteria analysis unto the relative weightings to be applied to the framework (Table 9).

Table 9: Final importance weightings applied to the indicator sets

Group	Weighting (%)	Ranking
Pedestrian Infrastructure	21.5	2
Physical Properties of sidewalks	23.2	1
Connectivity and convenience	18.7	4
Pedestrian Safety	20.2	3
Buildings and Land use	16.4	5

The scaling used for the threshold targets was set to represent what could be seen as realistic for the measurement of walkability achievement in respect of measuring energy efficiency. However, this can only be used as a guideline for the overall performance of any urban area, as the scaling does not take into account the fact thatthe evaluated scheme may have performed admirably in terms of some of the sub-groupingsof indicators whilst underachievingoverall.

Table 10: Percentage of total possible points on sliding scale

Group	Percentage range	Points total
Poor	<40	<1064
Average	40-49	1064.8- 1304.38
Average –Good	50-59	1331.0- 1570.58
Good	60-69	1597.2-1836.78
Good – Excellent	70-79	1863.4-2102.98
Excellent	>80	>2129.6

Table 11: Sliding scale technique

Group	Percentage Weighting	Number of indicators	Maximum points	Maximum points x weightings
Pedestrian Infrastructure	21.5	4	40	860
Physical Properties of sidewalks	23.2	3	30	696
Connectivity and convenience	18.7	2	20	374
Pedestrian Safety	20.2	2	20	404
Buildings and Land use	16.4	2	20	328
Total	100	13	130	2662

Conclusions

The comprehensive listing of indicators developed in this paper, together with the accompanying methodology on the points score, represents a significant advance in terms of quantifying energy efficiency within walkability measures. The baseline indicator approach adopted enables progress towards energy efficiency of any urban center to be monitored and any subsequent improvements to be measured. This provides the opportunity to further knowledge on the standards required to categorize an energy efficient urban center whilst highlighting the areas where, as yet, relatively few energy efficient targets exist. In the past, there has been a propensity to ignore indicators that required a more subjective or qualitative assessment, given that these tended to be more difficult to measure. As a result of the indecision regarding energy efficiency assessment, this paper highlights how walkability measures can be utilized successfully to frame the point scoringtarget-setting measures.

The comprehensive listing of indicatorsdeveloped in this paper, together with theaccompanying methodology on the pointsscore, represents a significant advance interms of quantifying energy efficiency within walkability.The baseline indicator approachadopted enables progress towards energy efficiency to be monitored and any subsequentimprovements to be measured. This providesthe opportunity to further knowledge on the standards required to categorize an urban center as energy efficient center whilst highlighting the areaswhere, as yet, relatively few energy efficient targets exist.The scaling used for the threshold targets was set to represent what could be seen as realistic for the measurement of walkability achievement in respect of measuring energy efficiency. However, this can only be used as a guideline for the overall performance of any urban area, as the scaling does not take into account the fact thatthe evaluated scheme may have performed admirably in terms of some of the sub-groupingsof indicators whilst underachievingoverall.Therefore, the comparison of each urban area against the threshold may besupplemented with an analysis for each subgrouping, where this research can be further developed in future.

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Assessment of Renewable Energy Technologies using Multi-Criteria Decision-Analysis: Input to a RE Technology Road-Map

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Abstract

A methodology developed, to assist establishing a structured framework for renewable energy technology road-map is presented. The main purpose of this study is to facilitate the creation of a systematic structure to prioritize different resource-technology-application options for achieving the national targets in Non-Conventional Renewable Energy (NCRE) development in electricity generation sector. Analysis of these options is evaluated in terms of implementation difficulty and time scale of implementation using selected set of criteria including technical, financial, social, environmental and other driving factors. The time scale of implementation is modelled as three development planning periods; short-term, medium-term and long-term, where wide application of the technology options can be expected at national level. The prioritization of the options is based on the Analytical Hierarchical Process (AHP) combined with a Weighted Sum Matrix (WSM). The application of the methodology and its outcomes are illustrated in a hypothetical manner. This model can be used to identify the potential gaps in knowledge, technology, market structure, regulatory and institutional, public acceptance and other challenges in implementation of programmes and projects. Furthermore it can be used for the preparation of future plans of renewable energy as well as to assist in policy making related to energy sector at large.

Keywords: Technology Road-Map, Renewable Energy, Analytical Hierarchical Process, Weighted Sum Matrix Model, Sustainability Criteria

Background

Fossil fuel (petroleum and coal), biomass and hydro electricity are the main energy sources in Sri Lanka. However, the fossil fuel share is rising day by day, increasing the dependencies on energy imports. Therefore, diversification of energy mix is imperative to strengthen the energy security with increasing penetration of indigenous Renewable Energy (RE). The National Policies indicate the target of electricity generation using Non Conventional Renewable Energy (NCRE) resources as 20 % by the end of 2020 while achieving 100 % electrification by 2015. Sri Lanka Sustainable Energy Authority (SLSEA) established on 01st October 2007, enacting the Act No. 35 of 2007, is the authorized agency, which promotes RE through information, regulatory intervention, promotion and facilitation of RE related project development, in order to realize above national targets.

Small hydro, solar, wind and biomass are the main NCRE resources with identified potentials and being harnessed for the electricity generation in Sri Lanka. The estimated electricity generation potentials of these resources are estimated about 800 MW, 8000 MW, 5500 MW, and 2500 MW, respectively [1]. It is also believed that there are significant potentials for other RE resources such as geothermal, ocean thermal, tidal and wave. However, resource assessment gaps of these resources still exist and the local adaption of the technologies cannot be expected in the near future, though these are well matured once at the global level.

The increasing demand for electricity and the inductive environment created by national policies related to electricity sector lead to a lucrative market for some RE resource based electricity generation. The advancement of Environmentally Sound Technologies (EST) in electricity generation could be integrated for the optimal utilization of these resources in a sustainable way. In spite of high availability of RE resources, barriers in implementation have become major concerns in harnessing RE resources for meeting the energy demand in the country. In this context, prioritization of different technologies in combined with the available resources for a particular energy service application is very important to achieve the national targets with an optimum manner, as determined by the appropriately selected sustainability criteria. Under the above circumstance, SLSEA has identified the requirement of establishing a structured framework for a RE technology road-map that guides the whole nation to an energy secure Sri Lanka in a sustainable pathway.

Renewable Energy Technology Road-map

A technology road-map is a plan that matches short-term, medium-term and long-term goals with specific technology solutions to help achieving those goals [2]. However, in a broader context, the development process of technology road-map for RE resources is more complicated as it requires attention to details in technical feasibility, economic viability, social acceptance and environmental conducive strategies. Nevertheless, this process reveals best practices, success stories and more importantly potential gaps in knowledge, technology, regulatory and institutional, public acceptance, market structural, or any other barriers in achieving the goals and milestones set by the national RE development plans. Further, this prioritizes different technologies based on "impact and effort" that facilitate to identify technology and related areas which have high impact with minimum effort to achieve intended target. Ultimately, the process would maximize the effective utilization of the RE resources for socio-economic and environmental benefits while enhancing energy security.

As the first step of preparing a technology road-map at national level, this study focus on developing a framework to evaluate various NCRE technologies' implementation difficulty and the time horizon in which wide applications is expected. In this study, the scope of the proposed framework limits to the electricity sector whereas selected NCRE technology applications are hydro (small/mini hydro, micro/pico hydro and low-head high-flow applications), solar (PV grid-connected large, PV off-grid, CSP), wind (offshore, onshore, onshore complex terrain) and biomass (off-grid, grid connected, MSW). Moreover this is an overall programmatic approach only and the impact assessments at project levels are not captured at this stage.

Multi-Criteria Decision-Analysis Techniques

Introduction

In recent years, some studies have concentrated on the use of Multi-Criteria Decision-Analysis (MCDA) for energy planning, policy making and even in the level of technology road-map developments. MCDA, is a branch of Operations Research, and comprises of a number of decision-making methodologies or tools. The commonly used MCDA methodologies include: Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), the Elimination and Choice Translating Reality (ELECTRE), Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Macbeth. Literature explains number of different applications of AHP in the energy sector as a model that can incorporate qualitative and quantitative information on RE resources. Thus it provides a way to deal with the complexity arising when the policy makers need to prioritize particular resource-technology-applications through screening out inconsistent judgments [3, 4].

Analytical Hierarchical Process for Evaluation of Criteria

AHP is a multi-criterion evaluation system developed in 1970's [5]. When adopting this methodology to the present study, three major steps could be identified [6];

- Problem decomposition as a hierarchy of levels with goal at the top level followed by categories of sustainable criteria, sub-criteria, technology applications and RE resources at the bottom most level, as illustrated in Figure 1.
- Comparative analysis where the relative importance of criteria is measured by the pair-wise comparison procedure
- Synthesis of priorities by computing priority weights of each criteria using eigenvector analysis.

The comparative analysis of this process is based on pair-wise comparison of alternatives (categories of sustainable criteria) which can be very subjective. Therefore, AHP uses a consistency check of comparisons. This consistency test helps to evaluate judgments made in pair-wise comparison. A Consistency Ratio (CR) of less than 0.1 is recommended whereas the pair-wise comparison should be repeated for a CR value greater than 0.1 till it achieves the level of consistency. The result of the AHP is forwarded to the weighted sum matrix for prioritization of resource-technology application options. It is very complicated to use AHP to analyze a large set of technology options and hence, a Weighted Sum Matrix Model is used.

Weighted Sum Matrix Model

The Weighted Sum Model (WSM) is one of the well-known techniques used in MCDA [7]. Although this is a simple approach, it's sound applications can be found in many decision making environments. WSM score of the matrix is obtained by evaluating each technology application against each evaluating sub-criterion. The resultant values of this process are the quantitative indicators of qualitative judgments on different RE resource-technology -application options.

Methodology

Categories of Sustainable Criteria and Assigning of Weights

As the first step towards developing this framework, five categories of sustainable criteria are selected, namely technical, financial, social, environmental, and other enabling factors. The influential and limiting factors for technology implementation are identified and categorized under above categories, as listed in Table 1. Weights are assigned to each sub-criterion ranging from 0 to 10 (defined as Ck_i ; $k = 1{:}n, i = 1{:}l$) while comparing the confrontation for technology implementation, where n is the number of sustainable criteria whereas l is the number of sub-criteria considered under selected k^{th}

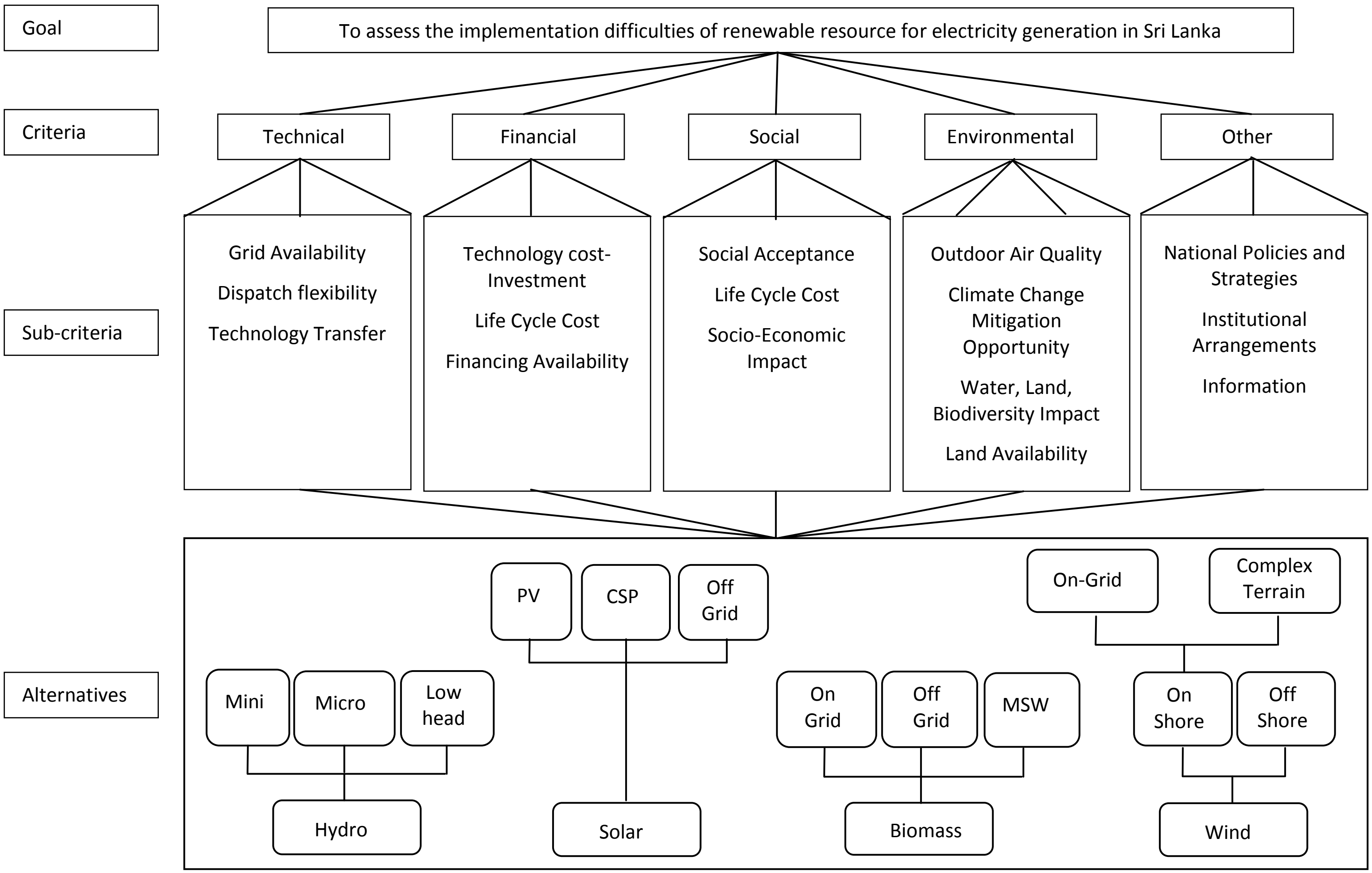

Figure 1: Criteria, sub-criteria and alternatives hierarchy

Table 1: List of sustainable criteria and sub-criteria

Categories of Sustainability criteria	Sub-Criteria (barrier for implementation)	Description	Scores
Technical (TC)	Grid Availability (TC1)	Technical limitations to expanding the grid to the locations where resources are identified, and to absorb the fluctuating RE	$C1_1$
	Dispatch Flexibility (TC2)	Difficulty of responding to the changes of the load variant.	$C1_2$
	Technology Transfer (TC3)	Limitations in technical skills, knowledge, capacity and facilities to deploy particular technology in commercial scale.	$C1_3$
Financial (FC)	Technology Cost–Investment (FC1)	Financial hindrance emerge due to the initial investment cost of particular RE technology	$C2_1$
	Life Cycle Cost (FC2)	Expenses associated with initial investment, operational, maintenance, expansions and rehabilitations. This may include payback period, IRR, LCOE.	$C2_2$
	Financing Availability (FC3)	Availability of finance and/or market based instruments	$C2_3$
Social (SC)	Social Acceptance (SC1)	The objections of the community, and of stakeholders (such as industry, non-governmental organizations, governmental and research organizations) to a project under a specific RE technology.	$C3_1$
	Socio - Economic Impact (Job/Value Addition) (SC2)	Limited opportunities for the develop community, do not create new jobs and value additions (direct or indirect).	$C3_2$
Environmental (EC)	Outdoor Air Quality (EC1)	Air quality degradation due to related technology	$C4_1$
	Climate Change Mitigation Opportunity(EC2)	Amount of greenhouse gas emission per unit electricity generation	$C4_2$
	Water, Land and Bio diversity Impact (EC3)	Adverse impacts on the quality, quantity of water, land and biodiversity	$C4_3$
	Land availability & accessibility (EC4)	Whether a technology (including the locations where the resources are located) leads to conflicting interests on land use; Renewable energy harness Vs. socio-economic development (Agricultural or urban development etc.)	$C4_4$
Other (OC)	National Policies & Strategies (OC1)	Inadequate national policies, strategies and set targets to promote RE technology applications	$C5_1$
	Institutional Arrangements(OC2)	Lack of institutional set up for successful implementation of RE technologies	$C5_2$
	Information (OC3)	Unavailability or limited access for stakeholders to data and information	$C5_3$

sustainable criteria category. For sub-criterion with higher resistance in implementation are given higher marks whereas, the lower marks are assigned for the criterion with less resistance.

The comparison can be done in several traditions, for example by means of either,

(1) a panel discussion of experts for a collective decision or

(2) individual stakeholder groups and then average (equal or weighted).

The mentioned stakeholder group could include relevant government authorities, private sector developers/investors, community-based organizations (CBOs), R&D institutes, Non-Government Organizations (NGOs) and financing institutes. Note that the selected sub criterions are indicative ones and may be revived based on experts suggestions.

AHP for Weighting the Categories of Sustainable Criteria

AHP is used to assign weight for selected categories of sustainable criteria by pair-wise comparing of each other and the aforementioned traditions can be used for the evaluation. The assigned weights represent the relative importance of sustainable criteria for technology evaluation.

The final weightings of each category $(PV_k; k = 1{:}n)$ then forwarded to WSM model. Among the other available options in weighing, the simplest way is to assign equal weights to each category while maintaining the summation of weights at 1.0, as illustrated in Table 2.

Table 2: Assigning weights for prioritization of key criteria

Categories of Sustainability Criteria	**AHP methodology (PV_k)**	**Equally Assigned Weights**
TC	PV_1	0.2
FC	PV_2	0.2
SC	PV_3	0.2
EC	PV_4	0.2
OC	PV_5	0.2
Sum	**1.0**	**1.0**

Weighted Sum Matrix Model for Technology Prioritization

The assigned weights to different sub-criteria ($C1_1$, $C1_2$, $C1_3$, $C2_1$, $C2_2$...etc) and calculated weights for categories of sustainable criteria (PV_1, PV_2...etc) are then considered for the WSM model. The level of difficulty in implementation of each resource-technology-application is assessed against each sub-criterion using four levels of scores, as indicated in Table 3. Next, the score values for each technology based on the criteria $(Sk_{i,u}\ ;\ i = 1{:}l, u = 1{:}m)$ are assigned. Notation $'l'$ denotes the total number of sub-criteria under the selected k^{th} category of sustainable criteria and $'m'$denotes the total number of technologies considered. The maximum weighted scores of each sub-criterion are calculated by multiplying the maximum score of 3, assigned for the highest level of difficulty by assigned weight (Ck_i). Sub-total of maximum achievable weighted scores of main category $(Sum_k\ ; k = 1{:}n)$ is calculated by summing up the maximum weight score values of relevant criteria.

Table 3: Levels of difficulty for technology implementation matrix

Level of Difficulty	**Score**[1]
None	0
Low	1
Medium	2
High	3

[1] Intermediate values are possible in evaluating

Similarly sub-total scores $(Wt_{k,u}; k = 1{:}n, u = 1{:}m)$ for each technology alternative under main category are calculated. Finally the normalized score for a particular category against a particular resource-technology-application option is calculated by the multiplication of priority value (PV_k) with the ratio of sub-total score $(Wt_{k,u})$ and sub-total of maximum weighted scores of the relevant main category (Sum_k). The total normalized score for a selected technology option $(N_u; u = 1{:}m)$ is obtained by the summation of normalized scores of all the main categories. Table 4 shows this process in matrix format. The normalized score values obtained are then used to locate the technology option in the technology roadmap.

Table 4: Matrix of criteria, sub-criteria and weighted scores

Categories of Sustainable Criteria	Sub-Criteria	Weights assigned for sub-criteria	Max. Weighted Score	Resource Technology	
				Assigned Weights	Weighted Score
k^{th}Sustainable Criteria Category	1	Ck_1	3* Ck_1	$Sk_{1,u}$	$Ck_1 * Sk_{1,u}$
	2	Ck_2	3*Ck_2	$Sk_{2,u}$	$Ck_2 * Sk_{2,u}$
	..	..	..	..	..
	l	Ck_l	3*Ck_l	$Sk_{l,u}$	$Ck_l * Sk_{l,u}$
Sub-total		-	Sum_k	-	$Wt_{k,u}$
Total normalized score				N_u	

Evaluation of the Development Planning Phase

The same method is followed to find the most appropriate time period for resource-technology-application options, while reducing complexity by selecting only two categories of sustainable criteria, namely technical and financial, and relevant sub-criteria in each. Note that it is important to select these sub-criteria such that they are independent from previously selected sub-criteria under the assessment of implementation difficulty as much as possible, and described in Table 5. The selected criteria are evaluated against each other considering the importance by using AHP.

Each technology is evaluated against selected sub-criteria using three different levels of effort for implementation; ranging from 0 (Minimum effort) to 3 (High effort) and finally the normalized values are obtained following the same methodology. The time axis is split into three horizons; short-term (2015-2020), medium-term (2021-2030) and long-term (2031-2050). Based on the sorted normalized values, the ranges for development planning phases can be selected as from 0 - 0.2 (short term), 0.2 - 0.5 (medium-term), and 0.5 - 1.0 (long-term) in the time horizon.

The results obtained through above analysis can be presented in graphical format as the graphical data summaries are more often easier to interpret and allow more information to be condensed into a smaller format than written format. Thus a bubble diagram, the most common graphical tool used in technology road-map process, is selected to represent different resource-technology-application options.

Table 5: Main criteria and sub-criteria used to decide the time axis

Sustainability Criteria	Sub-Criteria (barrier for implementation)	Description	Weight Notations
Technical (TC)	Technology Maturity (TC1)	Technology has been in use for long enough that most of its initial (technical) faults and inherent problems have been removed, and technology is commercially accepted	$W1_1$
	Technology Capacity (TC2)	Available technical skills, knowledge, capacity and facilities to either harness a particular renewable energy resource or deploy particular technology in commercial scale.	$W1_2$
Financial (FC)	Commercial Aspect (FC1)	Technology has wide commercial applications. Also the ability to convince / induce private (project) developers, investors and financing institutions	$W2_1$
	Financing Incentives (FC2)	Financing incentives are available for technology promotion (This could be established CO2 mechanism to feed-in-tariff to grant/aid for particular technology promotion)	$W2_2$

Two axes represent the level of difficulty in technology implementation (y axis) and technology deployment periods in which wide application of these technology alternatives are expected (x axis). The area of the bubble illustrates the primary resource potential available in the country which is an input to this model. Such resource potentials have to be obtained through RE resource inventory, which is partially completed at the moment.

An application of proposed methodology on five selected electricity generating RE technology options is illustrated in Appendix 1. The result of this illustration is shown in Figure 2 and Figure 3. According to these results, small hydro is the most favorable in terms implementation difficulty followed by onshore wind, solar PV, MSW and solar CSP respectively. Selected technologies can be ranked based on the level of difficulty in implementation if required. Figure 3 confirms that small hydro and onshore wind applications perform well in most of sustainable criteria.

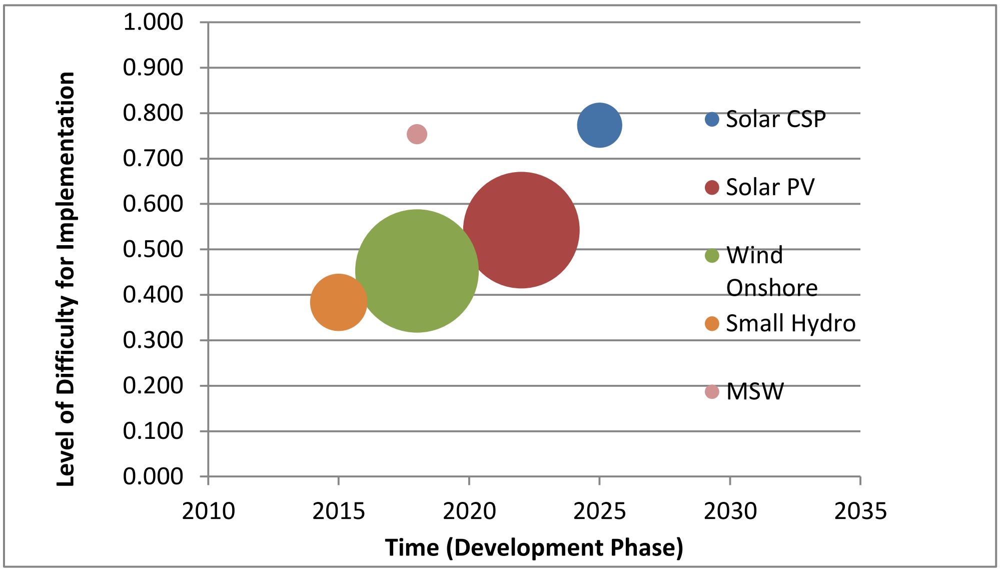

Figure 2: Implementation difficulty vs. time horizon for selected technologies

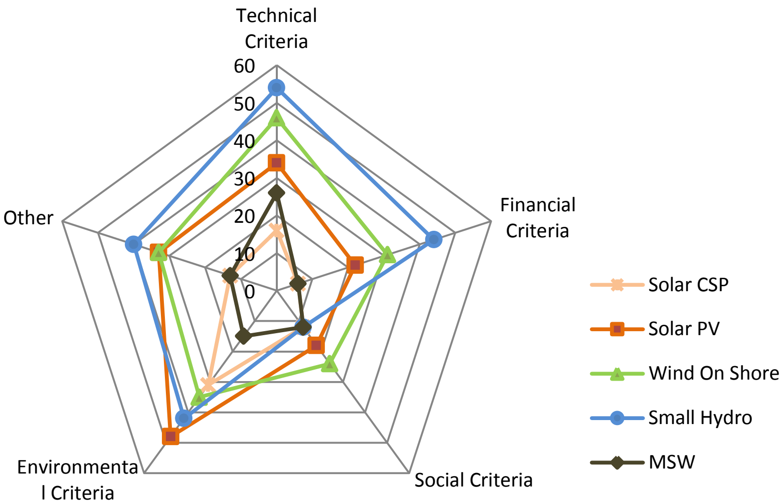

Figure 3: Performance of selected technology applications with respect to criteria

Discussion

In general, the judgments of experts are vague in RE related decision making process and adaptation of multi-criteria tools is critical for policy-makers and planners in order to perform detailed analysis from multi-perspective and obtain an optimal solution. This paper is concerned with using AHP and WSM criteria to create a framework to evaluate different resource-technology-applications used for electricity generation, specifically in terms of implementation difficulty. This methodology could be used to make a judgment; whether the selected RE technology applications perform equally well on all five criteria considered or incline towards one or few criteria. Policy and stakeholders who use this methodology should have a thorough understanding about the RE resource, technology, and applications to make a sensible decision. Their judgments and this process should be supported by sound information and data available in RE related literature comprehensiveness and applicability.

It is a challenge to establish mutually independent sub criterion for level of difficulty and time horizons. The engagement of stakeholders throughout the development phases of this framework is an important requirement. Proper monitoring and evaluating mechanism has to be established to facilitate feedback for continuous improvement of the technology roadmap.

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Appendix 1: Illustration Example

The tool developed to prepare technology roadmap is emphasized in this study through an illustration which has done for selected technologies solar CSP, solar PV, wind onshore, small hydro and MSW. The normalized value that represents the weight of the main criteria group can be obtained from AHP methodology. The pair wise matrix which should fill by the assistance of the experts is the basis for the calculation of normalized value and it is shown by the highlighted cells of Table 6.

The score of each sub criteria and the scores for each technology type against the sub criteria list under each of the major sustainable criteria, technical, financial, social, environmental, and other should be filled with the help of experts and the highlighted cells show the required fields to be filled. Table 7 shows the format of the weighted sum matrix which results total normalized values.

Table 6: AHP table for prioritizing categories of sustainable criteria

	TC	FC	SC	EC	OC	Principle Eigen Vector	Weighted Score
TC	1.0	2.0	3.0	4.0	5.0	2.605	0.429
FC		1.0	2.00	2.0	3.0	1.431	0.236
SC			1.0	1/2.0	3.0	0.758	0.125
EC				1.0	2.0	0.871	0.143
OC					1.0	0.407	0.067

Table 8: Total normalized score

Technology	Level of Difficulty for Implementation
Solar CSP	0.773
Solar PV	0.542
Wind Onshore	0.453
Small Hydro	0.383
MSW	0.754

The technologies are prioritizing based on the total normalized values such that relevant to the technology type that has less difficulty of implementation while highest value is relevant to technology type that has highest difficulty. The results are shown in Table 8.

The bubble diagram has drawn considering the total normalized value result from weighted sum matrix and the time horizon for each technology. Table9 shows the estimated total RE electricity potential of each technology and Figure 2 shows the bubble diagram obtained for the aforementioned technologies.

Table 9: Estimated RE resource potential

Technology	Potential (MW)
Solar CSP	500
Solar PV	3300
Wind Onshore	3700
Small Hydro	800
MSW	100

The star diagram has been drawn considering the difference between the maximum weight score and subtotal score of the each main sustainable criterion with respect to the each technology.

Table 7: Matrix of criteria, sub-criteria and weighted scores

Criteria	Weight	Max. Wt. Score	Solar CSP		Solar PV		Wind On Shore		Wind Off Shore		Wind OnShore Complex	
			Score	Wt Score	Score	Wt Score	Score	Wt Score	Score	Wt Score	Score	Wt Score
Technical Criteria												
TC1	10		3		3		1		3		2	
TC2	8		1		1		2		3		3	
TC3	9		3		1		1		2		2	
Subtotal Score - TC												
Financial Criteria												
FC1	9		3		2		1		2		2	
FC2	7		3		2		2		3		2	
FC3	6		2		2		2		2		3	
Subtotal Score - FC												
Social Criteria												
SC1	6		2		2		1		1		2	
SC2	6		2		1		1		2		2	
Subtotal Score - SC												
Environmental Criteria												
EC1	7		0		0		0		0		0	
EC2	5		1		1		1		1		1	
EC3	5		2		2		2		1		2	
EC4	6		3		2		2		1		2	
Subtotal Score - EC												
Other												
OC1	7		2		2		2		2		2	
OC2	7		3		1		1		3		2	
OC3	6		2		1		1		3		2	
Subtotal Score - OC												
Total Normalized Score												
Priority												

A Commonsense Knowledge System for Electricity Marketing Management

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Abstract

Policy makers should consider the social responsibility of households and individuals, as well as sustainability of energy conservation. Ecological innovations are in the focus of the analysis of electricity market restructuring: green power, fuel cells and wind energy converters for electricity market infrastructure are considered. Commonsense knowledge is the key to electricity market liberalization on the management of ecological innovations in electric utilities, in the process of information gathering into a formalized way. The aim of the approach is to identify the influences of decision-making process for electricity market liberalization on the management of ecological innovations in electric utilities. The findings should a) contribute to a better understanding of the transformation processes in the electricity sector and b) provide guidance for the development of frame-conditions that foster the development of a more sustainable energy supply system. This paper presents a novel tool, which is incorporated of modeling of commonsense knowledge in electricity market based on a modified version of Sugeno defuzzification technique. Effective decision-making in electricity market for classified knowledge has been derived by sugeno defuzzification technique based on an integrated Principal Component Analysis approach. It has been evaluated by using the concept of classification of human constituents in Ayurvedic medicine.

Key words: Restructuring and electricity market, Common sense knowledge, Principal component analysis, Sugeno defuzzification technique, Ayurvedic medicine

Introduction

Knowledge is the fundamental resource that enhances to function intelligently. Knowledge can be defined into two types such as explicit and implicit. Commonsense knowledge is one type of implicit knowledge [14]. Explicit knowledge can be presented formally and capable of effective (fast and good quality) communication of data to the user whereas implicit knowledge can be represented in informal way and further modeling needed for gaining effective communication. Three ecological innovations are in the focus of the analysis of electricity market restructuring: Green Power, fuel Cells and wind energy converters for electricity market infrastructure is considered [39]. But the analysis follows a qualitative approach mainly.

In this paper we present an approach to modeling commonsense knowledge in electricity market restructuring to analyze three ecological innovations effectively. This gives commonsense knowledge modeling approach for modeling commonsense knowledge in electricity market restructuring, which enables holistic approach for electricity market restructuring. At the initial stage principal component analysis has been used to model refinement. Modeling commonsense knowledge in terms of classification has been done using fuzzy logic at the second stage. The final stage of modeling commonsense knowledge has been conducted using expert system technology, which enables reasoning ability.

Knowledge

Knowledge originates in the minds of knowing subjects, who evaluate and interpret it in the light of the framework provided by their experiences, values, culture and learning. In the organizational context, knowledge takes a range of explicit forms and formats, including values, beliefs, emotions, judgments and prejudices. If properly applied, all forms of knowledge can provide the driving force for action [37].

Types of Knowledge

The two types of knowledge are generally known as explicit and tacit. In order to harvest the different types successfully, different strategies are required. Of the two concepts, explicit knowledge is what most people think of when the term 'knowledge' is used. This is because explicit knowledge is easier to understand than tacit knowledge, and easier to manage and manipulate [31][32][33]34]35]. Explicit knowledge is precise and able to be codified, while tacit knowledge is more intangible, involved with commonsense, it cannot be directly codified [15].

Ecological innovations in electric utilities

Market liberalization and upcoming competition fundamentally change the landscape in which economic development takes place in the electricity supply sector. Prices significantly decrease, new players enter the market, mergers and acquisitions lead to increasing concentration while, at the same time, new business opportunities emerge due to more service orientation. Moreover, the regulatory changes re-arrange strategic alliances of economic and political actors and give room for new policy styles [39]. From an ecological perspective, falling prices seem to significantly reduce environmentally benign options like increasing energy efficiency or enlarging the share of renewable energy sources. Still, electricity market restructuring may also create incentives for eco-oriented innovations on the fields of power generation and energy storage technologies, supply infrastructure, electricity demand or environmentally sound products [41]. The aim of the approach is to identify the influences of electricity market liberalization on the management of ecological innovations in electric utilities. The findings should a) contribute to a better understanding of the transformation processes in the electricity sector and b) provide guidance for the development of frame-conditions that foster the development of a more sustainable energy supply system [38].

Empirical and theoretical approach

Three ecological innovations are in the focus of the analysis: Green Power, Fuel Cells and Wind Energy Converters. The analysis follows a qualitative approach mainly. Interviews with employees from utilities in Germany, Switzerland and the Netherlands will provide the basis for case studies in the innovation fields mentioned above. The qualitative approach is addressed for following research questions [38].

Research questions

How to conceptualize the electricity supply system with regards to innovation processes?
What are conditions that may lead to radical changes?
What role do new products and technological innovations play in electric utilities?
How do electric utilities change as a consequence of market liberalization (organizational structures, culture, management etc.)?
What kind of innovation strategies do they pursue and which factors influence the emergence of certain strategy styles?
How does the management of innovation on the level of the firm affect changes in the electricity supply system?

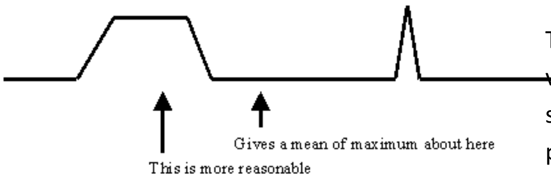
The study follows the reasoning of evolutionary economic theories (routines, selection environments, path-dependency, technological paradigms etc.) and also makes use of literature from the fields of strategic management and organizational theory (emergence of strategies, resource-based view of the firm, competencies and capabilities, explicit and tacit knowledge etc.) [40]. Therefore the analysis of electricity market restructuring has a problem of qualitative approach, because of tacit knowledge. This complicates the effective knowledge modeling of data to the user in support of electricity market restructuring.

Defuzzification

In many fuzzy logic applications, a crisp output is desired. To obtain a crisp value, the output fuzzy set must be defuzzified. Defuzzification is an important part in this research. Following are a few commonly used defuzzification methods.

Maximum Defuzzify

In this method the mean of the maximum values of a fuzzy set is taken as the defuzzification value. Note: this doesn't always work well because there can be *x* ranges where the *y* value is constant at the max value and other places where the maximum value is only reached for a single *x* value. When this happens the single value gets too much of importance in the defuzzified value.



Moment Defuzzify

Moment defuzzifies a fuzzy set returning a floating point (double value) that represents the fuzzy set. It calculates the first moment of area of a fuzzy set about the *y* axis. The set is subdivided into different shapes by partitioning vertically at each point in the set, resulting in rectangles, triangles, and trapezoids. The center of gravity (moment) and area of each subdivision is calculated using the appropriate formulas for each shape. The first moment of area of the whole set is then:

$$x' = \frac{\sum_{i=1}^{n} x_i' \cdot A_i}{\sum_{i=1}^{n} A_i}$$

where x_i' is the local center of gravity, A_i is the local area of the shape underneath line segment (p_{i-1}, p_i), and n is the total number of points.

Center of Area (COA)

Here, defuzzification finds the *x* value such that half of the area under the fuzzy set is on each side of the *x* value.

Weighted Average Defuzzify

This finds the weighted average of the *x* values of the points that define a fuzzy set using the membership values of the points as the weights. This value is returned as the defuzzification value.

Sugeno Defuzzication technique

This defuzzification method is very useful is when the fuzzy set is a series of singleton values. It could be that a set of rules is of the Sugeno type (1st order) format like:

If *x* is A and *y* is B then $c = k$

Where *x* and *y* are fuzzy variables and *k* is a constant that is represented by a singleton fuzzy set.
Most of the existing defuzzification methods make the estimation of a fuzzy set in an objective way. However, an important aspect of the fuzzy set application is that it can represent the subjective knowledge of the decision maker; different decision makers may have different perception for the defuzzification results. Although Sugeno method is considered as the most computationally effective, there is uncertainty about the defuzzified output, since it generates a singleton fuzzy set objectively and not well evaluated.

Methodology

We postulate a new methodology enhancing the ability of modeling commonsense knowledge for analysis of ecological innovations in relation to electricity market restructuring. Here we have addressed problems of data collections, information analysis and forecasting in electricity market knowledge infrastructure. The decision-making process has been conducted in a commonsense knowledge system based on Sugeno defuzzification method. Here, singleton functions in Sugeno defuzzification method have been computed by using an integrated principal components analysis approach. The process of the new approach is given in the following steps.

Acquiring Commonsense Knowledge

We begin with the fact that an analysis of electricity market restructuring. Three ecological innovations are in the focus of the analysis: Green Power, Fuel Cells and Wind Energy Converters play a critical role in electricity market restructuring. It is thus addressed in the first phase of commonsense knowledge modeling approach. In the first phase, commonsense knowledge about interviews is mapped into a questionnaire. As such, questionnaire based on interviews is considered as the input for the system.
Using the interviewing process between expert and knowledge engineer, commonsense knowledge has been acquired and mapped in to a questionnaire based on Likert scale technology [14]. I have chosen to acquire commonsense knowledge into a questionnaire since it is more convenient for further analysis. Once commonsense knowledge has been acquired then I should analyses the knowledge for finding dependencies. The questionnaire has been analyzed using principal component analysis (PC) [7] to find dependencies.

Principal components for commonsense knowledge modeling (Model Refinement)

Commonsense knowledge based questionnaires in pilot survey are considered for data analysis. The principal components analysis has been used to extract principal components from the data analysis.

Let *S* be the set of all questions in the questionnaire and *P* be the set of all extracted principle components.

For n number of extracted principal components, following computation is concluded.

$$X = \sum_{j=1}^{n} PC_j$$

Eq.1

$$\therefore X = \sum_{j=1}^{n} \sum_{i=1}^{m} a_{ij} S_i \qquad \text{Eq.2}$$

Statistical Fuzzy Inference – (Fine Tuning)

The questionnaire should be classified for the purpose of analysis of ecological innovations in electricity market restructuring in to Green Power, Fuel Cells and Wind Energy Converters. The output result for ecological innovations in electricity market restructure is generated based on classified knowledge. This enables to select the best ecological innovative. However, PC alone could not give a statistically significant classification for the tacit knowledge gathered through the questionnaire. I have used Fuzzy logic in Artificial Intelligence to fine-tune the derived answers by principle components analysis.

Classification of tacit knowledge is achieved by integrating PCA with Fuzzy logic. This is the key contribution in this approach, as PCA alone could not provide statistically significant classification for the commonsense knowledge. The selection of classified knowledge is based on Sugeno defuzzification process. This phase has been constructed by integrating output of model refinement with fuzzy inference system. It consists of following stages:

Fuzzfication

In this sub phase of Fuzzification, it basically analyses the fuzzy set and membership function for commonsense knowledge modeling. Membership functions have been constructed by using output of model refinement.

Let A be fuzzy set defined on a fuzzy concept using the interval of

$$\left[(X_{L1}...X_{U1}), (X_{L2}..X_{U2}),...,(X_{Ln}...X_{Un})\right]$$

Membership functions are defined as follows:

For $L_n = [X_{Ln}...X_{Un}]$

$$A_n(X) = \left(\frac{X - X_{Ln}}{X_{Ln} - X_{Un}} \right) \qquad \text{Eq.3}$$

Fuzzy rule base

Fuzzy rule base has been constructed by using the membership functions defined in fuzzification process.

Fuzzy rules have been constructed as follows,

Rule n. If $X>X_{Ln}$ AND $X<X_{Un}$

Then,

$$A_n(X) = \left(\frac{X - X_{Ln}}{X_{Un} - X_{Ln}} \right) \qquad \text{Eq.4}$$

Adding dynamically, in order to operate the reasoning process for answers given by the fuzzy rules, it can extend further into a fuzzy rule base.

Defuzzification

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. Defuzzification has been implemented using Sugeno-Type Fuzzy Inference.

Here $K_{1,}$ K_2...K_n are defined as singleton fuzzy sets.

Rule n.

If $A_n(X) = \left(\frac{X - X_{Ln}}{X_{Un} - X_{Ln}} \right)$

Then $Z = K_n$ Eq.5

Let Z be the output of rules defined in Sugeno-Type fuzzy inference

$$Z = \frac{A_1(X) * K_1 + A_2(X) * K_2 + ... + A_n(X) * K_n}{A_1(X) + A_2(X) + ... + A_n(X)}$$

Eq.6

Here $K_1, K_2...K_n$ are defined as singleton fuzzy sets have been constructed by output of model refinement.

$$K_n = \frac{(X_{Un} - X_{Ln})}{(X_{U1} - X_{L1}) + (X_{U2} - X_{L2}) + ... (X_{Un} - X_{U2})}$$

Results

I have evaluated our approach of modeling community decision-making by using Ayurvedic medicine as a domain with commonsense knowledge. In doing so, classification of individuals with commonsense knowledge through clinical examination in Ayurveda has been considered [5] [11][12][37]. The clinical examination of Ayurveda is divided into two paths, namely: examination through patient and examination through disease. Prescribing drugs for a disease depend on both 2 examinations. Classification of individual (human constituents) is included in examination through patient, which defined as a concept called '*prakurtipariksha.*'. Individual can be categorized into *vata*or*pita* or kapha based on the '*prakurtipariksha.*'. It was defined that one type can be dominated but in combination of all 3 types. In the exciting system, the method of analyzing constituents is not consistent. Although Ayurvedic practitioners use a questionnaire it leads to several problems like dependencies among the questions in the questionnaire and analysis of the constituent type. We addressed these problems in following steps. Here, extracting commonsense Knowledge in Ayurveda phase and removing dependencies phase have been implemented for community decision-making on the basis analysis of human constituents. This enables to give output of principal components based on commonsense knowledge modeling of the community consisted of Ayurvedic expert and laymen. Reasoning for derived human constituents phase implemented for Ayurveda decision-making approach, uses principal components as mentioned in earlier phase. This phase has been implemented by using FLEX expert system shell. This enhances Ayuveda decision-making approach to determine body constituent in percentage, details about other constituents in percentages, ranges of singleton fuzzy sets and dominated constituent type using Sugeno e fuzzification process of an individual in a community.

Extracting Commonsense Knowledge in Ayurveda

In the first instance we mapped commonsense knowledge regarding analysis of constituents to a questionnaire with an Ayurvedic expert. It is consisted of 72 questions to analyze *vata*, *pita* and *kapha.* It is shown as Figure 1.

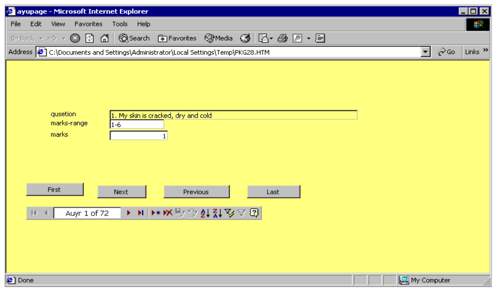


Figure 1: Questionnaire window

Removing Dependencies

A pilot survey has been done using a sample of 100 laymen for statistical modeling. Principal component analyzer has been used to remove dependencies. 25 principal components have been identified using SPSS [23] as shown below in a matrix form. Here V1, V2..V24, K1, k2..K24, P1, P2..P24 denotes question-numbering system in the questionnaire.

Cl

M =

		1	2 ..	24	25
V=	V1	-0.22862	0.249362 .	0.07395	0.058179
	V2	0.08431	0.20654 .	0.09719	-0.11279
	.				
	.				
	V23	-0.6458	0.232312 .	0.0067	-0.08396
	V24	-0.22215	-0.06453 .	0.07351	0.084404
K=	K1	0.012511	-0.09633 .	0.141314	0.25113
	K2	-0.00564	0.268145 .	0.17999	0.111715
	.				
	.				
	K23	0.409442	0.073812 .	0.11512	-0.05643
	K24	0.696973	0.126679 .	0.098213	0.045471
P=	P1	0.430044	0.14608 .	0.023669	0.09045
	P2	0.243781	0.373485 .	-0.04047	0.149644
	.				
	.				
	P23	0.009727	0.012529 .	-0.07222	0.177827
	P24	-0.37809	0.096985 .	0.158006	0.069821

Human constituents can be computed in to *vata, pita* and *kapha* in percentages as shown in Figure 2. Membership functions for *vata, pita* and *kapha*have been constructed using the out puts of principle component analyzer.

Classification of Human constituents

Human constituents can be computed in to *vata, pita* and *kapha* in percentages as shown in Figure 2. Membership functions for *vata, pita* and *kapha* have been constructed using the out puts of principle component analyzer.

Reasoning for Derived Human Constituents

This has been illustrated to determine body constituent in percentage, details about other constituents in percentages, possible diseases that can develop due to dominated constituent type, ranges of singleton fuzzy sets and dominated constituent type using Sugeno defuzzification process of an individual in a community. It is illustrated as shown in Figure 2, which has been implemented through FLEX expert system shell [16].

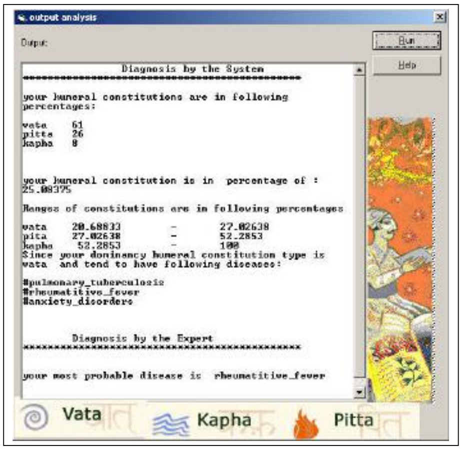


Figure2: Analysis and Reasoning window in Ayurvedic domain constructed using FLEX

Defuzzification

Defuzzification process has been computed using Sugeno – style inference technique:

Vata, pita, kapha with each of their computed value using PCA are analyzed in table 1.

Table 1: PCA analysis

Vata	Kapha	Pita
34.5512	29.8295 6	25.7175 1

Further K_1, K_2, K_3 are defined as singleton fuzzy sets

For, *Vata* constitution

K_1 = 42.550016 / (55.5856 + 107.53602 + 42.550016) = 20.68833

For *Pitta* constitution

k_2 = 107.53602 / (55.5856 + 107.53602 + 42.550016) = 27.02638

For *Kapha* constitution

K_3 = 55.5856 / (55.5856 + 107.53602 + 42.550016) = 52.2853

$$Z = \frac{A_1(X)*K_1 + A_2(X)*K_3 + .A_3(X)*K_2}{A_1(X)+A_2(X)+A_3(X)}*100$$

Z=output =25.08375

So body constitution is 25.08375 and concluded as value between *vata* and *pitta.*

Testing of diagnosis system

The expert system developed using this approach was tested with a sample of 30 persons of Ayurvedic experts and students (see Table 1).

Table 1. System testing: Expert vs. System

vata	pitta	Kapha	Expert_decision
25.71	20.71	53.57	KV
32.95	23.86	43.18	VP
39.88	23.81	36.31	VP
27.65	46.1	26.24	KP
25.69	29.36	44.95	KV
33.58	24.09	42.34	KV
25.71	34.28	40	KP
32.21	31.54	36.24	KV
22.51	29.8	47.68	KP
20.37	30.56	49.07	PK
30.6	35.52	33.88	PK
29.71	17.39	52.9	KV
41.07	10.71	48.21	KV
34.5	32.16	33.33	KV
23.46	28.57	47.96	PK
35.27	30.77	33.97	KV
42.36	36.11	21.53	VP
23.01	35.71	41.27	PK
47.94	19.86	32.19	KV
14.03	35.96	50	PK
19.15	36.88	43.97	PK
22.46	25.36	52.17	PK
40.47	26.78	32.74	PK
30.28	29.58	40.14	KV
12.71	44.92	42.37	PK
11.18	40	48.82	PK
11.24	40.24	48.52	PK
23.44	26.9	49.66	PK
17.09	36.75	46.15	KV
33.09	30.15	36.76	KV

The evaluation was conducted to see how far the answers generated by the system matches with the identification by Ayurvedic experts and the students. Further, the system's ability to fine-tune the answers was also tested. It has been investigated that 23 (77%) of conclusions matches with the system and expert, which leads to determine the accuracy of the system.

Transferring of the system into electricity market restructuring scenario

Testing of the framework through the commonsense knowledge domain of Ayurvedic medicine shows the feasibility of applying our approach for any domain with commonsense knowledge. With regard to any domain, one can acquire the tacit knowledge through a questionnaire and find the PC with the use of the system. Fuzzy Logic and reasoning modules work on the identified PC. In fact, beyond the acquisition of commonsense knowledge, the system is also automated to a large extent.

As per the electricity market restructuring too, we need to begin with acquisition of tacit knowledge pertaining to this particular domain. For example, several inputs described in the questionnaire for ecological innovations in electric utilities are required in order to take preventive measures through analysis in to Green Power, Fuel Cells and Wind Energy Converters. Measuring approach of these inputs are subjective and involved with commonsense knowledge. The system is capable of addressing the issue of modeling commonsense knowledge using three-phase knowledge modeling approach as described above. This concludes the capability of transferring of the system into electricity marketing management scenario.

In simple terms, with regard to any domain it is proposed to design a questionnaire to capture commonsense knowledge of a particular problem-solving scenario. Domain experts can do this. One can use our framework to enter such questionnaires and let the framework to come up with a fuzzy expert system for reasoning on commonsense knowledge.

Conclusions and Further Work

A Commonsense Knowledge system based on principal component analysis (PCA) and a statistical fuzzy inference system based on Sugeno deuzzification process have been used to determine output of fuzzy rules for modeling commonsense knowledge in community for decision making. It has been applied for classification of human constituents in Ayurvedic medicine. This has been convinced to determine body constituent in percentage, details about other constituents in percentages, ranges of singleton fuzzy sets and dominated constituent type using Sugeno defuzzification process of an individual in a community.

The system facilitated to derive constituents types in percentages while Ayurvedic experts obtain only the constituent type. As recommendation given by the Ayurvedic experts, determining constituent's types in percentages is an important criterion for prescribing drugs for a disease. Further, our system provide as an option to find out possible diseases. In generally, the system can be used as a self-assessment for finding constituents. According to Ayurvedic medicine, regiments can be done easily by knowing the constituent type. The human constituents can be computed as a combination. So it would help to find the effectiveness of minimum type in a diagnosis. At present the fuzzy-expert system that emerged from our research in modeling of Ayurvedic domain used at the System has been evaluated in faculties of Indigenous Medicine, University of Colombo and University of Kelaniya, Sri Lanka. This has gained an accuracy of 77%. Both Ayurvedic consultants and Ayurvedic medical students use this expert system.

With these results of applications of the framework, this appears to be more general and customizable for any domain. As an immediate step of further work, we intend to get a questionnaire of commonsense knowledge pertaining to electricity marketing management domain and customize our system for reasoning in a novel manner. We also intend to make the system available as a web application that is accessible by general public. Therefore, we conclude that our framework can be used as a generic approach to develop fuzzy experts systems for reasoning in domains with commonsense knowledge.

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Challenges and Prospectus of adopting the ISO Standard on Sustainability Criteria for Bioenergy

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Abstract

This standard has been developed with the objective of facilitating the assessment of environment, social and economic aspects of sustainability. The major areas of concern are green-house gases (GHG), water quality and quantity, soil quality and productivity, air quality, biodiversity, energy efficiency, waste, human right, labour rights, land use right and land use change, water use right, fair business practices, financial risk management, traceability and comparability. This standard contains specific Principle, Criteria and Indicators (PCI) for each area of concern. One of the major challenges faced by local economic operator is the lack of records that are needed to prove the conformity with the relevant requirement. Another challenge is the resource limitation such as financial, technological, human resource required to improve the present status of the industry or operation. However, it is recognized that improving market competitiveness globally and adopting this standards would improve the long term sustainability of Sri Lanka by contributing socio-economic development.

Introduction

National, regional and international Bioenergy Standards are essentially the consensus distillation of successful thinking, experience, research and development, presented as good practice and minimum requirements. They have proven to be a very successful means of ensuring optimal performance, safety, economy in trade, sustainability, and compliance with regulations.

The production and use of bioenergy have potential roles in mitigating climate change, promoting energy security and fostering economic and social development. Various types of biomass are used for the production of bioenergy through many types and sizes of economic operations. Assessment of sustainability of bioenergy becomes an important aspect in the long term development of the bioenergy sector. As every country in the world produces and consumes some form of bioenergy, the characteristics of bioenergy production are very heterogeneous, and their production processes depend on several factors, such as geographic location, climatic conditions, level of development, institutional frameworks and technological issues. In response to the growing international interest in bioenergy, and lack of globally harmonized sustainability criteria, the International Organization for Standardization (ISO) has decided to form a standard for sustainability criteria for bioenergy.

ISO is the world's largest developer and publisher of International Standards. Its member bodies are the national standards institutes of 165 countries, one member per country, with a Central Secretariat in Geneva, Switzerland, that coordinates the system. Its standards development work is conducted by Technical Committees (TC) and Sub-Committees (SC) which meet every year or so and are attended by formal delegations from participating members of that committee. In practice, the technical work takes place in Working Groups (WG) of experts, nominated by national standards committees but expected to act as independent experts. Most national standards bodies set up 'mirror committees' to coordinate their input to the international work. Sri Lanka Standards Institute (SLSI) is the ISO member body in Sri Lanka.

Preparing International Standards is normally carried out through technical committees referred to as ISO/TC. Each member body interested in a subject (for which a technical committee has been established) has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

ISO Sustainability Criteria for Bioenergy

To assist in understanding the current and future position with standard, it is worthwhile reviewing the work of technical committee on sustainability criteria for bioenergy, ISO/TC 248, previously practice and experience in successful standardization from standard writers/experts from different countries. Further each of these ISO physical meeting process illustrates the value of a clear worthwhile objective, wide representation, top technology, successful operation and real cooperation. The main purpose of the work of the ISO/TC 248 is to write a proposed ISO 13065 Sustainability criteria for bioenergy standard that provide a flexible, practical framework for considering the environmental, social and economic aspects that could be used to evaluate bioenergy production, supply chain, and application, and to facilitate comparisons. Further, the Standard aims to promote the sustainable production and use of bioenergy while facilitating trade. The application of this International Standard will enable users to identify areas for continual improvement in the sustainability of bioenergy.

The development of ISO 13065 Sustainability criteria for bioenergy standard was originated from a proposal of Brazil and Germany in the year 2008 (in which the title was "Sustainabilitycriteria for biofuels"). A majority of voting ISO members agrees with the proposal,but suggested to start as a preliminary project. Subsequently in June 2009, a preliminary meeting was held in Berlin, Germany, where the present title was agreed upon with the scope of "Standardization in the field of sustainability criteriafor production, supply chain and application of bioenergy". This includes terminology and aspects related to thesustainability (e.g. environmental, social and economic) of bioenergy. The new work of ISO/TC 248 which is a welcome major step for continual global improvement is also described. This work aims to determine best balance of global standard.

The final objective was to achieve another ISO standard adding to the already existing 19,500 international standards. There is no question that standards can do wonders and elevating quality, productivity, safety across all areas of products and services to a higher level with a strong commonality in performance which indeed can benefit us across countries rich or poor.

Criteria development is tricky and even more so with sustainability. In fact still if you ask a direct question how sustainability looks and feels, answering can be quite difficult. Big countries and big powers will think quite different to small and less developed countries and those who are about to be submerge due to climate change. For the latter the criteria should be applied to others on how they work and play as they are going under for no fault of theirs but more due to excessive consumption and selfishness of some others. In this particular instance it was deciding on sustainability criteria for all players across the bio energy value chain. Understand the bio energy value chain and you can contemplate the challenge. Around 2007 and 2008 the world witnessed rising fuel prices as well as food prices and a connection was discussed. What we heard in this meeting was that the direct connection or the nexus is not clear and that there is no scientific clear evidence of such a link and hence bio energy can be considered without food security entering into the picture.Delinking food security from energy security is quite interesting and can have far-reaching consequences. The land use can be considered independently and even a single plot undergoes change what it would mean is that there is no opportunity lost for the other and no problem to the wider community.

The criteria can address anyone within the value chain and each party can considered to be an economic operator. The nature, scale, abilities, attitudes, work ethics and inner power can vary across these economic operators. The front end economic operator is the person who will grow or produce raw material for the bio energy value chain. In Sri Lanka an albeasia grower or a restaurant chain yielding waste cooking oil can be classified as economic operators. On the other side a refinery owner or a biomass power plant too are economic operators. Now the sustainability criteria should consider all different aspects of these operators and their physical locations and operations.A refinery owner can influence across a wider group as they would be influencing long-distance farming including where and by whom. One element which will not be disputed is the mandatory consideration of social, environmental and economic elements in deriving the criteria. How well and comprehensive you address social and environmental linkages and performances will mean the accuracy of your work and the honesty of your purpose.

It is with strong participation that one can influence as well understands forces and ideas at play and the meeting opened up our eyes in many ways. It is important to understand that if we are to grow our food, live our lives and grow our energy too from the same land mass, competition has to come in some day. This International Standard specifies sustainability principles, criteria and indicators for the bioenergy supply chain to facilitate assessment of environmental, social and economic aspects of sustainability.This International Standard is applicable to the whole supply chain, parts of a supply chain or a single process in the supply chain. This International Standard applies to all forms of bioenergy, irrespective of raw material, geographical location, technology or end use.This International Standard does not establish thresholds or limits and does not describe specific bioenergy processes and production methods. Compliance with this International Standard does not determine the sustainability of processes or products.This International Standard is intended to facilitate comparability of

various bioenergy processes or products. It can also be used to facilitate comparability of bioenergy and other energy options.
33 environment indicators are identified in this standard. These 33 indicators collectively represent how bioenergy systems may affect environmental sustainability with respect togreen house gases, water quality and quantity, soil quality and productivity, air quality, biodiversity, energy efficiency and waste [1].
23 social indicators are identified in this standard. 23 indicators identified under human right, labour rights,land use right and land use change and water use rightcategories collectively represent how bioenergy systems may affect social sustainability [1].
6 economic indicators are identified in this standard for fair business practices and financial risk management[1].

Biomass Energy sector in Sri Lanka

Sources of Production of Biomass

Biomass comes in different forms. Following are the most common forms of biomass available in Sri Lanka [2].

- Fuel wood
- Municipal Waste
- Industrial Waste
- Agricultural Waste

General biomass conversions are given in Table 1

Table 1: Biomass Conversions

Primary Source	Conversions
Firewood (natural yield, home gardens, dedicated woodlots)	Thermal energy for boilers to generate steam for industry uses and electricity generation and combustible gases to drive Internal Combustion engines for electricity generation
Coconut Shell	Charcoal, activated carbon; mostly for export as a non energy product
Bagasse	Thermal energy to generate steam for boiler-turbine units used for electricity generation
Wood	Charcoal; mostly for the hotels and household markets

Biomass energy

Biomass is the most common source of energy supply in the country, of which the largest use is in the domestic sector for cooking purposes. Due to the abundant availability, only a limited portion of the total biomass use is channeled through a commodity market and hence the value of the energy sourced by biomass is not properly accounted. However, this situation is fast changing with many industries switching fuel to reduce the cost of thermal energy. As a result, a sizable fuelwood supply is emerging to supply the new demand, albeit many questions on sustainability [2].

Fuel-wood was also the mainthermal energy source for many industries,including the agro sector (tea,rubber, coconut, sugar, etc.), the manufacturingsector (brick, tile, lime, etc.)and the commercial sector (bakeries,hotels and restaurants). Further, therewere several small-scale industrieswhich used bio-energy, such as pottery,ceramics, chemicals, metal, leather,textiles, soap, road tarring, distilleries,crop and fish drying, laundries andpaddy parboiling. These users will continueto depend on biomass fuels becauseof low purchasing power andlack of availability of other more preferredfuel systems [3]. In Sri Lanka, as inmost other countries, energy planningis concentrated at the national level andfocuses mainly on commercial fuels.Such energy planning does not accommodatesite-specific issues, especiallythose related to supply and demand.Consequently, the importance of biomass as a sustainable energy source as well as the issues associated with the development of the sector hasbeen largely undervalued by plannersand policy makers.However with this current ISO 13065 standard site specific sustainability aspect can be addressed and if that bioenergy facility conforms to this standard, certification also can be done.

Biomass conversion technologies

There are wide ranges of biomass utilization technologies that produce useful energy from biomass. The commonly used techniques for utilizing biomass are elaborated below.Direct combustion of raw biomass is the simplest method of extracting energy with lowest cost, and therefore is the most common too. However, such a use emphasizes the worst features of biomass-bulk and inconvenience. Therefore, it is required to convert into a form that is more convenient. This may involve simple physical simple physical processing or upgrading to a variety of secondary fuels (solid, liquid or gas) by means of certain conversion processes, including;

- Combustion after relatively simple physical processing, which may involve sorting, chipping, compressing and/or air-drying
- Conversion of biomass into intermediate fuels (gaseous or liquid) by natural biological processes
- Conversion of biomass into intermediate fuels (solid, liquid or gaseous) by action of heat under control conditions.

The first method in principle is directly concerned with primary fuels. Second method consists of exposing biomass to certain microorganisms. The secondary fuels produced are the results of metabolic activity of the microorganisms. Production of Ethanol and Biogas are the two most common biological conversion processes. In third method, biomass is subjected to appropriate temperatures and pressures in theabsence of oxygen. Pyrolysis is the basic process in this method. The biggest advantage of gasification is the variety of feed stocks as well as products. The produced synthetic gas can be utilized not only as the fuel for power generation but also as the feedstock for chemical industry [4].

Adaptation of proposed ISO 13065

In order to obtain the maximum benefit of biomass for the energy sector in Sri Lanka it is essential that the sustainability concept to be incorporated in all the aspects. For such improvements, above standard could be adapted to local context. However this requires careful consideration of the issues and challenges faced by the local industry in complying with the requirements laid down by the proposed standard.

This International Standard provides a harmonized approach for the assessment of sustainability rather than providing threshold values. It takes into account the work of other relevant ISO standards, published and under development. As part of the development of this International Standard an inventory was taken of other sustainability initiatives. This International Standard aims to promote the sustainable production and use of bioenergy while facilitating trade. It is hoped that the application of this International Standard will enable users to identify areas for continual improvement in the sustainability of bioenergy.

Prospectus

From the experience with these standards, it is seen that all technologically advanced countries and almost all others recognize the value of good standards (including Codes, Guides, test methods, product standards, process standards, or other statement of requirements) because they;

Openly and clearly specify fair uniform technical and some administrative requirements to greatly facilitate communication, discussion, debates, agreement, consensus based, trade and application between the various parties often involved.

1. Cover the views and needs of those contributing to and affected by the standards.
2. Form a repository for global wisdom and current good practice valuable as a basis for training.
3. Provide level of food safety, energy security, economy and performance which readily satisfy the needs of policy makers, planners, manufacturers, testing and inspections bodies, purchasers, users as well as regulatory authorities, workers and the public.

4. Are used as the basis of sound contracts, regulatory requirements and litigation.
5. Provide the most practical, economic and equitable method of achieving the above.
6. Do not retard progress or competition because of frequent revision in light of experience and R & D
7. Benefit to about 200 countries and their people through
8. All the advantages which apply to all other successful ISO standards
9. Greater input which improves the quality of the standard.
10. Overall cost are reduced when the process is optimized
11. The ISO 13065 standard, having greater acceptance and use, improves economies for all countries involved.
12. Avoid or resolves many import/export problems and reduces trade barriers.
13. Improve relations between participating countries
14. Facilitates standardization and provides valuable guidance for participating and non-participating countries.
15. Eases the transfer of technology and acceptance of personnel between countries-increasingly important with the shrinking world.
16. Facilitate globalization by major bioenergy users and suppliers and compliance with WTO principles.
17. Reduces duplication in developing and maintaining many bioenergy national standards.
18. Be referenced in regulation, national standard, contracts or product data.
19. A valuable guide in training and education.
20. Help rationalize difference between “America” and “European” outlooks.
21. Help unify world practice (not necessarily immediately but in the long term) e.g. terminology. This will help in computer programs, reports etc and globally improve economics and avoid confusion and errors.
22. Be based on world best practice and successful experience.
23. Deal with the range of bioenergy forms and depth agreed by ISO/TC 248.

Challenges

Today, the current civilization is recognized as computer based civilization. Computers which support two way communications between man and a machine are quite unlike the technologies of mass communications. However, computer based systems and applications are developing so rapidly that it is hard to predict what will come next. This evolutionary process explains the gradual changes in human capabilities that have been instrumental for changing production and consumption patterns for humankind

from ancient to present time. However, despite numerous radical, technological, improvements, human poverty has increased, widening the gap between the rich and poor globally and locally.
Both, overconsumption and under-consumption (unsustainable production and consumption) pose daunting challenges to human development and ecosystem stability. The kind of sustainability criteria standard required at the macro level to address the present global crises is not limited to a particular sustainability standard like this. The ISO standards should be able to promote behavioral changes of the world community locally (nationally), regionally and globally to resort to more sustainable production and consumption pattern to safeguard our common future. “Development Theme” is still mostly viewed as economic development nationally and internationally while few countries recognize “Happiness” as a guiding principle of development.

Food-Fuel nexus

Our concern is the use of food as primary source of bioenergy. Use of non-food biomass should be the first option. Food vs energy issue should be resolved. It was proposed not to include food as a source as bioenergy, since the use of food is non-sustainable and to ensure that food security is not jeopardized. If food is to be included, it should be taken from waste or leftovers instead of fresh source.Committeenoted above idea, however it is decided that "this International Standard applies to all forms of bioenergy, irrespective of raw material, geographical location, technology, or end use".

There can also be the possibility of a grower switching supplying soybean from a food commodity market to an energy commodity market though the person will essentially continue growing the same crop.
These two scenarios can be multiplied across and the cumulative effect should be visible after a certain level of operations. It is not right to say that there is no effect – there may not be an immediate observable effect – as a result of different land use. The effect as with food may not be in the immediate neighbourhood as the switching may actually increase the prosperity of a local area as the switching is primarily because of an economic benefit. It is in this context that during the meeting the adoption of the concept of ‘local food security’ was contested by the Sri Lankan group as the definition of local was limited to the area that is surrounding the site and its activities. These discussions and lack of consensus meant that the proposed standard still stays as a committee draft. It may be true that there is no absolute connection identified between food security and bio energy as yet with the commercial bio energy movement being somewhat in its infancy, however the real truth is that it is not at all possible to state positively that there is no link. There is a significant knowledge deficit and that needs to be addressed quite fast to prevent adverse

decisions being made citing ignorance or due to ignorance.

Green house gases (GHG)

Both, over consumption and under-consumption (unsustainable production and consumption) pose daunting challenges to human development and ecosystem stability. If the biomass has alternative fates, the alternative fate of that material shall be documented (e.g., land fill, waste incineration, or decomposition on a field). The alternative fate should be included in the system boundaries of that alternative system and the associated emissions should be counted there, because the emissions and removals from this system do not occur in the bioenergy system. This procedure constitutes system expansion and should be the preferred approach. Alternatively, allocation may be used to estimate the GHG intensity.

The fact is that as yet bio energy is not mainstream energy in countries. This is true with many developing economies as bio energies do not operate in the domain of commercial energy. With globalisation and with increased demand for reducing GHG emissions one can grow your energy elsewhere and proceed to source or have carbon accounting. Where the energy is grown, if the offer is attractive, one may witness the shift of land for more opportunistic bio energy than for food or other use.

Water use, quality and quantity

Sri Lanka will not become a country of water scarcity since the per capita water availability is adequate for the estimated peak population. In addition, the available water resources are sufficient for food security, water supply and sanitation and other users such as bioenergy if the resource is managed judiciously. However, there is an issue with the availability of water in the space and time due to climatic variability of the country. Therefore, it is important to make an assessment of the needs of different uses and users and availability of water resources at the river basin/provincial/district levels so that future strategies for water resources conservation, development and management could be formulated and followed base on this sustainable development principles, criteria and indicators of this standards. There are four indicators that EO should address under the water use right and five indicators, the EO should address under the water quality and quantity.

The above inference is made assuming that the existing water resources are being protected and managed for future generations. Therefore, all other sectors which have either direct or indirect impact of water resources are expected to perform their mandated responsibilities. For example, protected areas network in Sri Lanka needs to be conserved and managed by the Forest Department and Wild life Conservation Department to ensure that the headwaters of rivers are not disturbed.

Streams and tank/reservoir reservations need to be looked after by the local authorities and the Irrigation Department/Mahaweli Authority of Sri Lanka, respectively. Central Environment Authority (CEA) needs to enforce and regulate the water quality of water bodies in coordination with respective institutions.

Large number of legislations and institutions with overlapping responsibilities is one of the reasons for most of the issues facing when taking approval for the new bioenergy facility. Therefore it is important to review the existing legislations and institutional arrangement and initiate an institutional reform work. Some of the institutions which were created in the past for specific purposes are no longer effective and hence considered redundant. It is very difficult to close these redundant institutions as politically this becomes a very difficult proposition. However, this institutional reform process is needed to effectively manage the water resources in Sri Lanka in the new millennium.

None of the above could be achieved without adequate resources. There is a dearth of qualified trained professionals in the water sector institutions due to brain drain, retirement of those who stayed back and difficulty of recruiting and keeping them due to poor remuneration.

Soil quality and productivity

In Sri Lanka, 14 land degradation processes have been identified as significant issues which are soil erosion, soil fertility decline, pollution, salinization, alkalization, dystrification, eutrofication, compaction,crusting and sealing, water logging, lowering of the soil surface, loss of productive functions, loss of active land surface and aridification. Out of those, soil erosion and soil fertility decline are the two main degradation processes taking place in the country. Recent estimate indicate that 50% and 30% of agricultural lands in Sri Lanka have been degraded due to soil erosion and declining fertility, respectively.

Excessive quantities of soils are lost due to cultivation of some erosion inducing crops such as tea, potato, tobacco and vegetables without adopting adequate soil conservation measures. In contrast in the same environment, soil erosion losses are negligible in some other lands having well managed tea, pasture, Kandyan forest gardens and natural forests. Hence, selection of appropriate land uses and adoption of recommended soil conservation measures has become a sustainable approach in checking soil erosion. However many social constraints exist for such a land use change. Therefore, adoption of appropriate soil conservation measures has been recommended in ISO 13065 for existing bioenergy facility as well as new bioenergy facility in Sri Lanka. The measures such as stone bunds, lock and spill drains, trees and shrub, terraces, individuals and common flat forms are more suitable for farming components. Agronomic measures such as contour plowing, quick land preparation, contour planting, mulching, organic manure use,

use of controlled irrigation systems and crop residue management are also recommended to check soil erosion.

In order to ensure continuation of satisfactorily adoption of above soil erosion conservation measures on farming lands, a sustainable soil conservation approach has been introduced by ISO/TC 248 sustainability criteria for Bioenergy, ISO 13065. The approach includes conducting research to generate technology, establishing technology demonstrations, training famers and technical officers on new technology, making farming community aware on the importance of soil and water conservation, providing farmers with cash and material incentives to establish conservation measures and making use of the legal provisions under the soil conservation related act to control illegal earth excavations.

Numerous provisions have been embodied in different enactments to control land degradation in general and soil erosion in particular. The more important enactments are Forest Ordinance (1907)and amendments, Land Development Ordinance (1935) and amendments, Fauna and Flora Protection Ordinance (1937) and amendments, State Land Ordinance (1947) and amendments, Soil Conservation Act (1951) and amendments, Rubber Control Act (1956) and amendments, Tea Controls Act (1957), Water Resources Board Act (1964), Land Grants Special Provisions Act (1979), State Lands (Recovery of Possession) Act (1979), Agrarian Services Act (1979) and amendments, Mahaweli Authority Act (1979) and amendments and National Environment Act (1980) and amendments .

Waste

Although scope covers total spectrum of bioenergy, under the main body total emphasis is on usage of energy crops and associated problems. It was not considering the organic waste (organic component of municipal solid waste, crop residues, farm animal waste, and other organic liquid waste, sewage and biosludgeect..) as a bioenergy option. Actually in some cases the sustainability of the boenergy option is strengthened when streams are used together rather than in isolation (eg shredded biowaste with biomass leaves, sewage with kitchen biowaste). Then ISO/TC 248 committee decided to accepte it and inter alia subclause about time periods takes secondary raw materials into account.

Land use change

For a smaller country when the competition rises one has to understand that the land has to surrender from one to another. It is the process that will be arrested with defined criteria as much more consensus would be sought rather than proceeding only through economic leverage.

Today land is becoming a lucrative investment opportunity and the evidence points to a new gold rush. Once a high yielding resource is identified, there are always many interested parties who will move in as the society is not full of sustainability practitioners but more with speculators. A global land rush is on with far more complexity with significant global security implications and it is important that we do understand the dynamics. In land we put our faith and trust for our living. The issue is when the same plot has to serve the needs of many from afar as well!

Indirect Effects

We believe there is need to define indirect effects asthese are discussed under the standard. We areconcerned that with the current definition of directeffects there will be effects directly connected to thebioenergy process that are lost as a consequencethat those are not, what could be considered, in thedirect control of the economic operator. Futher establishingbioenergy systems can lead to GHG emissions andbiodiversity loss and it can be associatedwith land use change and land tenure change. Economic, environmental and social effects thatmay not be directly associated with the bioenergyprocess under analysis. Ecological communities are shaped by acomplex array of direct and indirect interactions.These interactions are spatially and temporallydynamic. Indirect effects, can be defined as theimpact of one organism or species on another thatis mediated or transmitted by a third. In other words,A (donor) has an effect on B (transmitter), whichthen affects C (recipient). There are two main waysby which an indirect effect can occur. The first isknown as an interaction chain, in which a donorspecies affect the abundance of a transmitter andhas an effect on a recipient. The second, interactionmodification, occurs when the donor species alterssome other attribute of the transmitter, such asbehavior. Human interaction with ecologicalcommunities can influence a complex array of directand indirect interactions.Bioenergy systems may cause indirect effects inother production systems. Two indirect effectsreceived much attention: indirect land use leading toGHG emissions and biodiversity loss, and indirectimpact on food prices determining the availability offood for the poor.Land use indicates what crop is grown on the landand land tenure is defined as who has access to theland. Establishing bio-energy system can beassociated with land use change, for example fromfrom subsistence farming to cash crop. As land uschange, the tenure aspects change as well.Likewise, with higher land and crop values, changesin land access from small holder farming to largescale biofuel plantations might take place.

Conformity Assessment

From a general point of view we think that the systems of ensuring knowledge on origins of products and the up stream impacts related to sustainability aspects needs more elaboration in the standard.We also support that it should be made more eplicit to what extent auditing of the information provided from the standard would be managed.

For example if one economic operator in a value chain does not have third party auditing, the information along the whole value chain will be affected.
Link is included in note at chain-of-custody definition. Keep in mind that this document cannot impose who is assessing conformity or judge the value of conformity assessmentISO/TC committee noted, traceability will only bebriefly addressed in thisstandard; additionalinformation may be included inseparate document related toconformity assessment.

Ecosystem Services

Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits."
Today, it has become a challenge for industrialized countries to reverse the trends of their unsustainable production and consumption patterns based on resource intensive production systems and infrastructure development exceeding the carrying capacity of global ecosystem. At the same time, other countries including the countries with emerging economics having over 80 percent of the world population are facing unprecedented challenges to ensure the well-being of their population within a shrinking environment space. Under globalization no signal country will be able to face these challenges in isolation.
At this stage, it is worthwhile to note a comparison of the manmade rules through constitutions with physical laws of nature, made. In the functioning of the ecosystem, the rules are governed by nature itself.

Child labour

Age for child labour is not defined in this international standard. In the developing countries child labour is still prevalent. By not mentioning age, there is flexibility and EO can take advantage of this ambiguity. It is noteworthy that Employers in developing countries particularly Asian countries in favour of child labour, they justify that it reduce the cost of production of many export commodities and make them competitive in international market.
In reality these business exploit children by paying very low wages and earn more profit without investment in human capital. Another important point to be noted if children from lowest income families were not involved in work, they may be misled and fall into wrong hands and could be used in unproductive activities used by anti-social elements.
Child labor continues to exist on a massive scale, sometimes in appalling conditions, particularly in the developing world. Child labor is an immensely complex issue. It cannot be made to disappear simply by the stroke of a pen.

Traceability

Intense discussions has occurred within PC 248,especially within WG1, on how (and if) to addresstraceability in this standard. Traceability is part of conformity assessment. Considering all positionsreceived on traceability andhaving heard the explanationsat WG 1 meeting, it is decidedto maintain traceability in thestandard using the currentwording. Traceability is important as it helps to find out whether it originates from a sustainable source. Not all the bioenergy feedstock comes from the bigenterprise which is easy to trace back. We have toconsider about it, since it will be difficult and costlyto have the certificate related to traceability. It willpotentially despise the small holders of bioenergy.It will be Impossible to facilitate comparisons if traceability is left out and also the standard since is not primarily addressing one single process but a chain of processes.When an economic operator wants to present results, it shall supply specific information and data concerning all processes, modules under its financial or operational control.The economic operator should collect generic information and data for those modules not under its financial or operational control, but necessary to supply complete information to the next operator in the value chain.The information shall be presented in a transparent way.Traceability is not required when this Internationl Standard is applied to a single process or module. The traceability is also an integrated part if an economic operator in the last step of the supply chain want to add sustainability data to their operations. In the present form with the present PCIs there is need for traceability to be treated in the standard.

Comparability

To facilitate comparison is though important. To make comparisons before an internal company decision is of course necessary and such comparison can be made without too deep information. The risk for misjudgments is then up to the company.

This standard does not include an enough comprehensive and detailed framework to make possible comparisons between all various energy options, since bioenergy, fossil energy and other alternative options are very heterogeneous as stated in the "Introduction". Thus, this standard should facilitate comparisons by its harmonized approach, including transparency and documentation.

There are many indicators that are missing to be able to facilitate a fair comparison between options, and that is more important than that some of the bioenergy indicators does not apply. It may also facilitate comparison between bioenergy processes or products with other energy options. For other energy options than bioenergy it has to be acknowledged that there are principles, criteria and indicators missing since this standard is about bioenergy only.

It is not evident why detailed information acquired within the process should be reduced to score card format information. As some certifiers at the end of the value chain might want to have a rather complete picture to assess whether it meets their requirements, we prefer communication rules that ask for comprehensive information. However, a combination of score card and comprehensive information seems viable.

The use of this International Standard for comparison between various energy options (both bioenergy and non-bioenergy) is optional. If sustainability parameters of an energy option is to be compared with the parameters of another energy option, all sustainability indicators in this International Standard should be considered. Any gaps in information should be justified and documented in a transparent way as provided in this International Standard for each indicator and for system boundaries. If comparison is done, each indicator should be assessed by applying this International Standard in a consistent manner. The complete results should be provided for any comparison.

The sustainability of an energy option that is compared cannot be determined based solely on the use of this International Standard. No statements or communications about the sustainability of an energy option should be made based on the use of this International Standard. The comparison of the GHG impact for bioenergy and the energy source it would replace is required by this International Standard to assess the overall GHG impact. The use of this International Standard for comparison of other indicators between various energy options (both bioenergy and non-bioenergy) is optional.

Other challenges

1. Different languages, Culture, Standardization system and level of Biomass energy technology and environmentally sustainable technology. For use in local industry translation and local reprinting will be needed.
2. Increased overall cost, if high tech is used to measure indicators (Eg; Air modeling to calculate emission due to Biomass)
3. Reduced national ownership, commitment and accountability.
4. Difficult in resolving major differences. Eg; Food-Fuel-Land nexus that can significantly affect socio-economic development.
5. Increased complexity and cost in keeping standard up-to-date with materials, technical, legal and social developments.
6. Slower progress due to lack of competition and incentives for innovation and R and D.
7. Difficult of getting all countries to be willing to accept the same status of the draft. (Eg; CD 13065 had to be reintroduced as CD2 for balloting)

8. Access to information is barriers due to formal very strict company procedure
9. Lack of primary data on particular Bioenergy project for comparability (clause 8) and traceability (clause 7).
10. As we use conventional technologies, we need technology transfer for energy efficiency (clause 5.4.6) and maximized productivity
11. Present waste management (clause5.4.7) practice are not sustainable in general, therefore appropriate best practices has to be adopted.
12. Lack of experience of economic operator and or government on the business to set threshold values
13. This International Standard provides principles, criteria and indicators. The principles reflect aspirational goals while the criteria and indicators address sustainability aspects and the information that is to be provided. However, the indicators in this International Standard might not comprehensively capture all sustainability aspects for all bioenergy processes.
14. Reporting Sixty two indicators are challenging.
15. Lack of expertise/local capacity who knows both bioenergy and conformity assessment
16. Information management gaps
17. Lack of coordination within sectors
18. Absence of case studies on success stories and demonstration projects
19. Lack of tested business model for financing

Conclusion

The proposed ISO/PC 248 Sustainability Criteria for Bioenergy standard could be considered as pioneering effort of ISO Secretariat and its member countries to insure that bioenergy sector contribute to the economic development while ensuring sustainability. If adapted, use of such a standard for the local bioenergy sector would help not only the economic operator but also the other stakeholders including consumers to realize the relevant objectives. Adaptation of proposed ISO standard for bioenergy to suite with local context, without scarifying the overall concept of sustainability, would contribute to long term sustainability of the energy sector while contributing to the social economic and environment sustainability. However there are host of challenges for local industry in adopting this standard, which are related to technical, financial, capacity gaps and political will.This International Standard can be used in several ways. It can facilitate business-to-businesscommunications by providing a standard framework that allows businesses to “speak the same language”when describing aspects of sustainability. Purchasers can use this International Standard to comparesustainability information from suppliers to help identify bioenergy processes that are fit for a defined purpose.Other standards, certification initiatives and government agencies can use ISO 13065 as a reference for howto provide information regarding sustainability. This International Standard does not provide threshold values.Threshold values can be defined by economic operators in the supply chain and/or other organisations (e.g.government). Sustainability information provided through use of this International Standard can then becompared with defined threshold values to determine whether a process fulfils the conditions for the intendeduse. These challenges need to be addressed prior to implement the said standard.

Acknowledgement

The author would like to thank the chairman and members of Sri Lanka National Mirror Committee on Sustainability Criteria for Bioenergy for encouraging him to do this work.

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Assessment and Mapping of Biomass Consumption in Tea Industry

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Abstract

Sri Lanka Sustainable Energy Authority is in the process of compiling comprehensive resource maps for renewable energy resources, with the intention of preparing resource inventories that serve as databases on deployable resources for energy generation. As a sub programme for biomass resource inventory, assessment and mapping of biomass energy consumption was done by the authors, and this paper presents the findings related to biomass consumption in tea industry. This study comprises of analysis of data at regional level (i.e. Divisional Secretary Division), and the outcomes are presented in form of maps, prepared through EnerGIS 10.0 software. Sample survey method was used for data collection and extrapolated to regional level. Special analysis and mapping of biomass supply areas and pricing was done in the study as well, in order to study any location based issues in biomass supply for tea industry.

Keywords: Tea Industry, Firewood, Specific Fuel wood Consumption, EnerGIS, Resource assessment

Introduction

Sri Lanka Sustainable Energy Authority (SLSEA) has the core objective of developing renewable energy in the country. Thus SLSEA performs the task of preparation, maintenance and updating of an inventory of all renewable energy resources in Sri Lanka, so that all stakeholders are equipped with credible data on resource availability. Comprehensive resource maps are being compiled on solar, wind, hydro and biomass energy resources, and thereafter resource inventories will be compiled based on deployable amount available for energy applications.

As a renewable energy resource, biomass holds the prominent place in primary energy supply. In fact, biomass supplied 209.9 PJ of primary energy, equivalent of 43.5% of total primary energy supply in 2012[1]. Comprehensive resource assessment for biomass should include the sub components of assessment and mapping of biomass availability/ land use, biomass consumption, Waste Agricultural Waste (WAB) & Municipal Solid Waste (MSW) as energy resources. The study of assessing and mapping biomass consumption of the country is under way, considering end users, i.e. industrial sector (including small and medium industries), commercial entities, household sector and the most recent stakeholder, i.e. power plants.

Importance of biomass energy is major due to its numerous benefits. Under proper management, biomass offers wide range of benefits to a nation. Biomass technology is environmental friendly in terms of net carbon emissions, biomass is cost effective than fossil fuel, local farmers get economic benefits, retain national wealth, technology is available for a wide range of capacity, etc..

However there exists a highly competitive market for biomass. Major reasons identified are the parallel demand of SMEs/micro industries (like brick, bakery, tile, lime, pottery, smoked rubber, dairy, etc.), increasing trend in switching from fossil fuel to biomass in the industrial sector and the cooking energy requirement. This competition could be threatening to the biomass resources due that the supplier (vendor) chains of biomass are highly informal. Under these informal set-ups, deforestation might also take place. When the growth of biomass does not compensate the rate of cutting or when forest cover is affected, environment will be degraded hectically. Trees are the protector of water resources & soil. Thus deforestation affects other natural cycles adversely, destroy eco systems and have additive effects on carbon dioxide emissions. Therefore biomass energy utilization should be done in a way that it makes a benefit to the environment and not a burden. Thus it is very important that the biomass used as energy should be derived from a sustainable source (in terms of qualitative measures and quantitative measures), comply to Environmentally Sound Technologies (EST) and be traceable.

Tea industry is one of the major industries using biomass. Therefore the assessment and mapping of biomass consumption related to tea industry has a significant importance, and this paper/survey aims to analysis this biomass consumption pattern in tea industry in comprehensive way.

Tea industry is a prominent industry in terms of attracting foreign exchange, which exceeded 1.5 Billion USD in 2013. Moreover, approximately 10% of the total population find their livelihood through this industry [2]. The tea industry is categorized by the elevation of the plantation, i.e. high grown, medium grown and low grown. The plantations are classified as estates and smallholdings. There are around 400,000 numbers of small holdings accounting for 120,955 hectares of tea cultivation. There are 286 Regional Plantation Companies and 35 state plantation companies cultivating 82,065 hectares [3]. The tea leaves plucked from these plantations are then processed in tea factories. In Sri Lanka, there are 717 tea factories active stage [5], either “bought leaf” factories or the factories that use tea from their own cultivations.

The tea industry faces many barriers, difficulties and threats, such as change in global demands, competition with other tea producing countries, changes in rainfall, issues related to manpower, etc.. Furthermore, rising energy costs is also reported as a serious concern in tea industry. Before 70’s, fossil fuel was much cheaper and convenient than biomass. Escalation of oil price has made tea industry to sacrifice 19 kg of made tea in order to purchase a barrel of oil. (A decade ago, this value was 10 kg of made tea per barrel of oil) [4]. As a result, almost all tea factories switched to biomass from fossil fuel. Under these circumstances, tea industry is reported as a high consumer of biomass.

Objectives of the study

When analysing the behaviour of biomass consumption, the following results were expected from the study.

[1] Overall biomass consumption for Sri Lankan tea industry

[2] Biomass consumption for tea factories in each Divisional Secretary Division (DSD)

[3] Price of fuel wood in each DSD, w.r.t. different fuel wood types

[4] Biomass supply areas for different regions in the country.

These results are important for a policy maker due to following reasons: Overall biomass consumption for Sri Lankan tea industry is necessary to compare it with other industries, and to see the impact of tea industry on total biomass demand. The most important and the time consuming activity in this study was the analysis of regional data, which is needed to determine the regional demands for biomass, and to identify whether there are location based issues in biomass supply and demand. Price of fuel wood was also analysed, to see any relationship between biomass pricing according to fuel wood types and the location of consumption. Fuel wood supply areas were identified, to identify the patterns of biomass supply across the country for tea industry.

Methodology

Fuel wood

Firstly, Specific Fuel wood Consumptions (SFWC) of 46 factories were measured through sample survey method, covering all tea growing districts. This sample accounted for 9.73% of the total tea production in Sri Lanka (2012). Secondly, with the help of Sri Lanka Tea Board, the contact details of registered tea factories were found together with their respective production of made tea in 2013. Thirdly, all tea factories were mapped with the use of Geographic Information System (EnerGIS) software. Fourthly, the tea factories were sorted according to Divisional Secretariat Division (DSD) and the production figures of each DSD were calculated. Finally, the production figure was multiplied with the average value obtained for specific fuel wood consumption for Sri Lanka, and the amount of fuel wood used in tea factories were calculated and mapped to Divisional Secretariat Level.

Sawdust

Some tea factories have switched to alternative forms of biomass like sawdust, briquettes, etc. Saw dust consumption was calculated through Boiler Manufacturer Data and was verified whenever possible through communicating with the respective tea factory.

Type of Fuel wood used, Price and Biomass Supply Areas

These details were obtained through direct communication to the factory list, given by the Tea Board. Although 717 number of tea factories are registered under the Tea Board, majority of them have not provided telephone numbers/emails. Some phone lines were not reachable or even changed. Somehow the project team managed to obtain details of 102 factories on biomass types, supply areas, prices of each fuel wood type, sizes of fuel wood used, fuel wood storage methods, and problems with fuel wood supply & use. Thereafter the details were analysed and mapped through EnerGIS.

Assumptions based for the calculation

- Tea produced by all factories is of “Orthodox” type. (Other tea types also consume the same amount of thermal energy).
- Extra 5% of production records at Sri Lanka Tea Board have been added to the study to compensate the production losses or any other losses at factory, like rework, testing, distribution to staff, etc.
- When saw dust consumption was calculated according to boiler manufacturers, 1 TPH capacity boiler has a saw dust consumption of 0.26 ton/hr; number of working days 321; no of working hours 24.

Results and Discussion

Amount of Biomass Consumption

The specific firewood consumption that was obtained from analysis of the industries under this survey was 1.97 kg firewood per kg of made tea. This is higher than the SLSEA baseline value (2010) of 1.78 kg firewood per kg of made tea. The best value observed by SLSEA so far was 0.56 firewood per kg of made tea, observed in the Harangala Tea Factory, Kataboola, Nairajapitiya. The major energy saving measures practised in Harangala Tea Factory are installation of a heat recovery system to recover the heat from the flue gas and pre-heat the intake air up to ~100 °C using the recovered heat. Furthermore, good management practices are being followed by all the staff. The total consumption of firewood for tea industry in Sri Lanka was 705,000 MT of firewood plus 41,800 MT of saw dust. The highest tea production is observed in the months of February to May and October to December. Thus the biomass demand is also high in these months of the year.

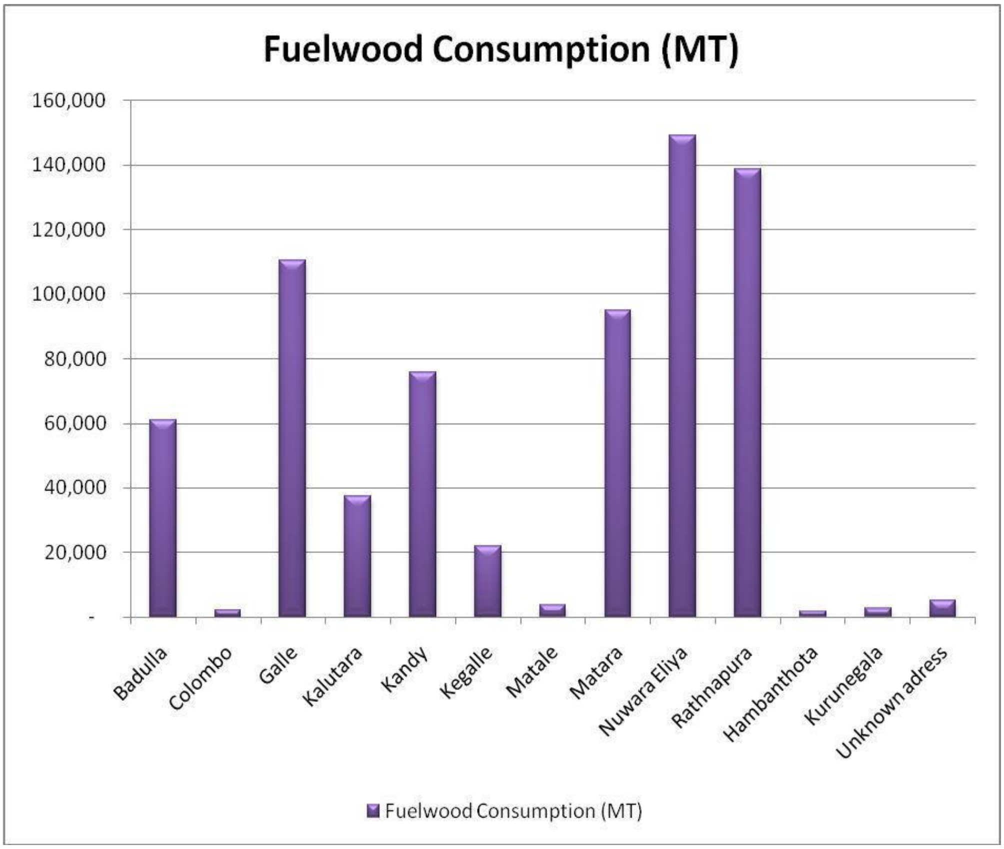

Figure 1: District-wise fuel wood consumption in MT

The data were graphically presented to the District level (figure 1) and Divisional Secretariat level (Figure 2 – Map of Biomass Consumption in Tea Industry). The highest firewood consumptions were found in Ambagamuwa DSD (60,007 MT), Nuwara-eliya DSD (54,325 MT) and Kotapola DSD (34,670 MT). The total savings potential of firewood w.r.t SLSEA baseline was 67,800 MT and w.r.t. best case, it was 503,100 MT. Saving potential of fuel wood on District basis is given in the figure 3. The summary of results is tabulated in the table 1.

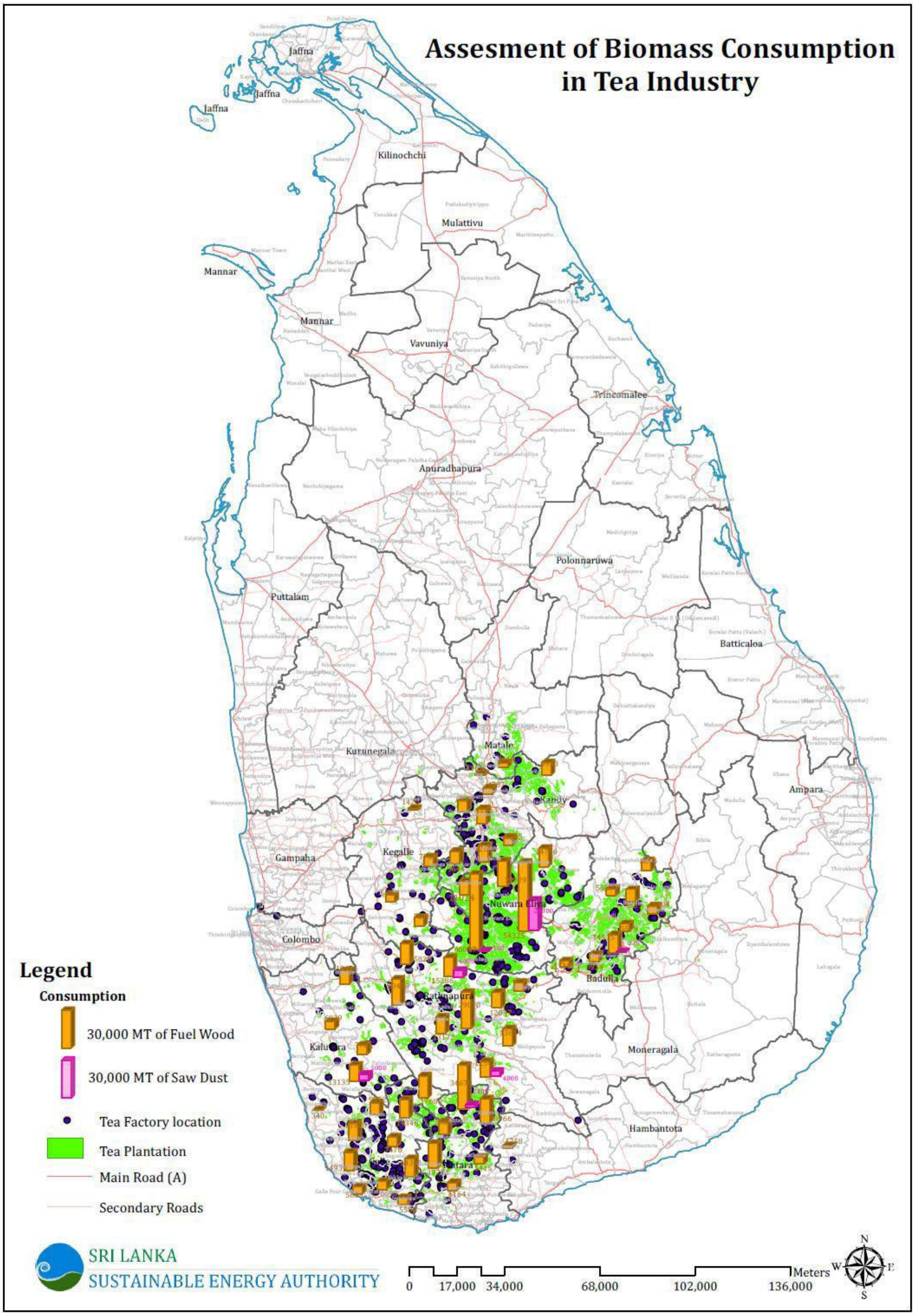

Figure 2: Map of biomass consumption in tea industry

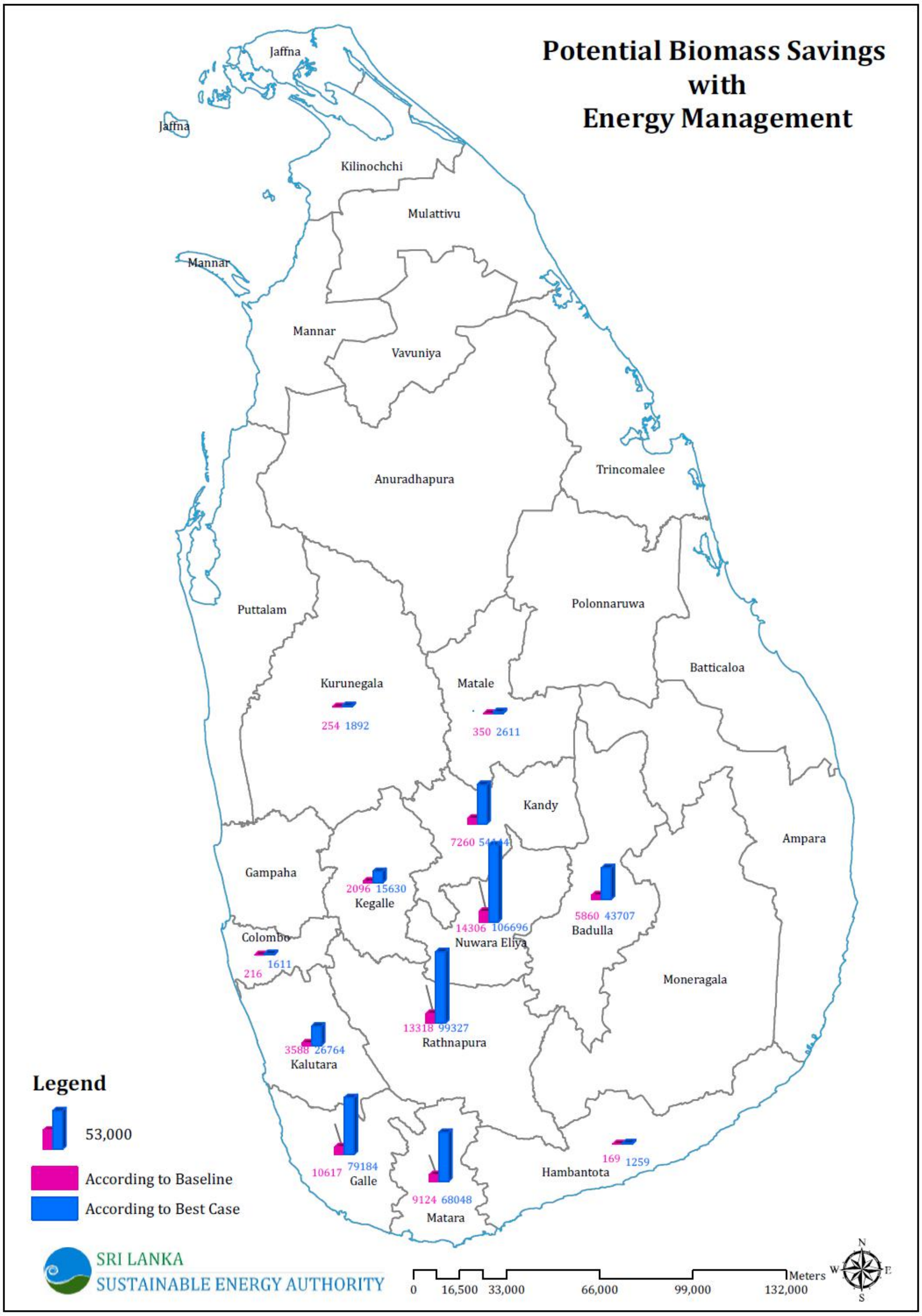

Figure 3: Saving Potential of firewood in tea industry

Table 1: Fuel wood consumption and savings (MT/annum) in Sri Lanka, according to District and DSD

Divisional Secretariat Division	District	Fuel wood Consumption (MT)	Fuel wood Savings (MT) w.r.t. SEA Baseline	Fuel wood Savings (MT) w.r.t. Best Case
Lunugala Meegahakivula	Badulla	8,074	775	5,781
Soranathota Hali Ela	Badulla	5,687	546	4,072
Welimada Haldummulla	Badulla	4,991	479	3,574
Badulla	Badulla	9,839	945	7,045
Haputhale	Badulla	5,934	570	4,249
Bandarawela	Badulla	14,515	1,393	10,393
Passara	Badulla	6,404	615	4,585
Ella	Badulla	5,599	538	4,009
District Total	**Badulla**	**61,043**	**5,860**	**43,707**
Hanwella Kolonnawa	Colombo	2,250	216	1,611
District Total	**Colombo**	**2,250**	**216**	**1,611**
Bope-Poddala Galle Four Gravets	Galle	5,653	543	4,048
Welivitiya-Divithura Elpitiya	Galle	13,918	1,336	9,965
Karandeniya Balapitiya	Galle	340	33	244
Hikkaduwa Baddegama	Galle	14,939	1,434	10,696
Habaraduwa Imaduwa	Galle	5,588	536	4,001
Yakkalamulla	Galle	14,391	1,382	10,304
Nagoda	Galle	7,470	717	5,349
Thawalama	Galle	14,346	1,377	10,272
Neluwa	Galle	17,680	1,697	12,659
Akmeemana	Galle	6,695	643	4,794
Niyagama	Galle	9,572	919	6,854
District Total	**Galle**	**110,592**	**10,617**	**79,184**
Ingiriya Bulathsinhala Millaniya	Kalutara	11,383	1,093	8,150
Madurawala Mathugama	Kalutara	5,080	488	3,637

Divisional Secretariat Division	District	Fuel wood Consumption (MT)	Fuel wood Savings (MT) w.r.t. SEA Baseline	Fuel wood Savings (MT) w.r.t. Best Case
Palindanuwara Agalawatta	Kalutara	7,781	747	5,571
Walallawita	Kalutara	13,135	1,261	9,405
District Total	**Kalutara**	**37,379**	**3,588**	**26,764**
Panwila Medadumbara Udadumbara	Kandy	9,933	954	7,112
Gangawata Korale Udunuwara	Kandy	12,063	1,158	8,637
Delthota Doluwa	Kandy	6,585	632	4,715
Pathadumbara Harispattuwa	Kandy	4,787	460	3,427
Poojapitiya Akurana	Kandy	1,164	112	833
Ganga Ihala Korale Udapalatha	Kandy	21,441	2,058	15,352
Pasbage Korale	Kandy	11,024	1,058	7,893
Yatinuwara	Kandy	8,624	828	6,175
District Total	**Kandy**	**75,621**	**7,260**	**54,144**
Kegalle Rambukkana	Kegalle	1,420	136	1,017
Bulathkohupitiya Aranayaka	Kegalle	7,706	740	5,517
Yatiyanthota Dehiovita	Kegalle	5,688	546	4,073
Deraniyagala	Kegalle	7,016	674	5,023
District Total	**Kegalle**	**21,830**	**2,096**	**15,630**
Rattota Yatawatta Ukuwela	Matale	3,646	350	2,611
District Total	**Matale**	**3,646**	**350**	**2,611**
Kotapola	Matara	34,670	3,328	24,824
Pasgoda	Matara	18,966	1,821	13,580
Akuressa	Matara	19,771	1,898	14,156
Pitabeddara	Matara	10,053	965	7,198
Mulatiyana	Matara	5,415	520	3,877
Athuraliya Malimbada	Matara	6,164	592	4,413

Divisional Secretariat Division	District	Fuel wood Consumption (MT)	Fuel wood Savings (MT) w.r.t. SEA Baseline	Fuel wood Savings (MT) w.r.t. Best Case
Weligama				
District Total	**Matara**	**95,039**	**9,124**	**68,048**
Nuwara Eliya	Nuwara Eliya	54,325	5,215	38,897
Ambagamuwa	Nuwara Eliya	60,007	5,761	42,965
Kothmale	Nuwara Eliya	19,929	1,913	14,269
Walapane Hanguranketha	Nuwara Eliya	14,756	1,417	10,565
District Total	**Nuwara Eliya**	**149,017**	**14,306**	**106,696**
Kalawana Kolonna	Rathnapura	12,546	1,204	8,983
Imbulpe Rathnapura	Rathnapura	22,040	2,116	15,781
Kahawaththa Pelmadulla	Rathnapura	29,010	2,785	20,771
Ayagama Elapatha	Rathnapura	20,478	1,966	14,662
Weligepola Godakawela	Rathnapura	13,614	1,307	9,748
Opanayaka Balangoda	Rathnapura	12,037	1,156	8,618
Kuruwita	Rathnapura	15,828	1,519	11,333
Nivithigala	Rathnapura	13,172	1,265	9,431
District Total	**Rathnapura**	**138,725**	**13,318**	**99,327**
District Total	**Hambantota**	**1,758**	169	1,259
District Total	**Kurunegala**	**2,642**	254	1,892
Unknown address		5,208	500	3,729
Total Fuel wood Consumption in Sri Lanka MT (round off value)		**705,000**	**68,000**	**505,000**

Price of fuel wood

Tea industry uses the following types of fuel wood

- rubberwood
- gliricidia
- junglewood
- teak (off cuts)
- eucalyptus (off cuts)
- calliandra
- turpentine
- mango
- grevillia
- pruned tea
- gum tree
- factory wastes

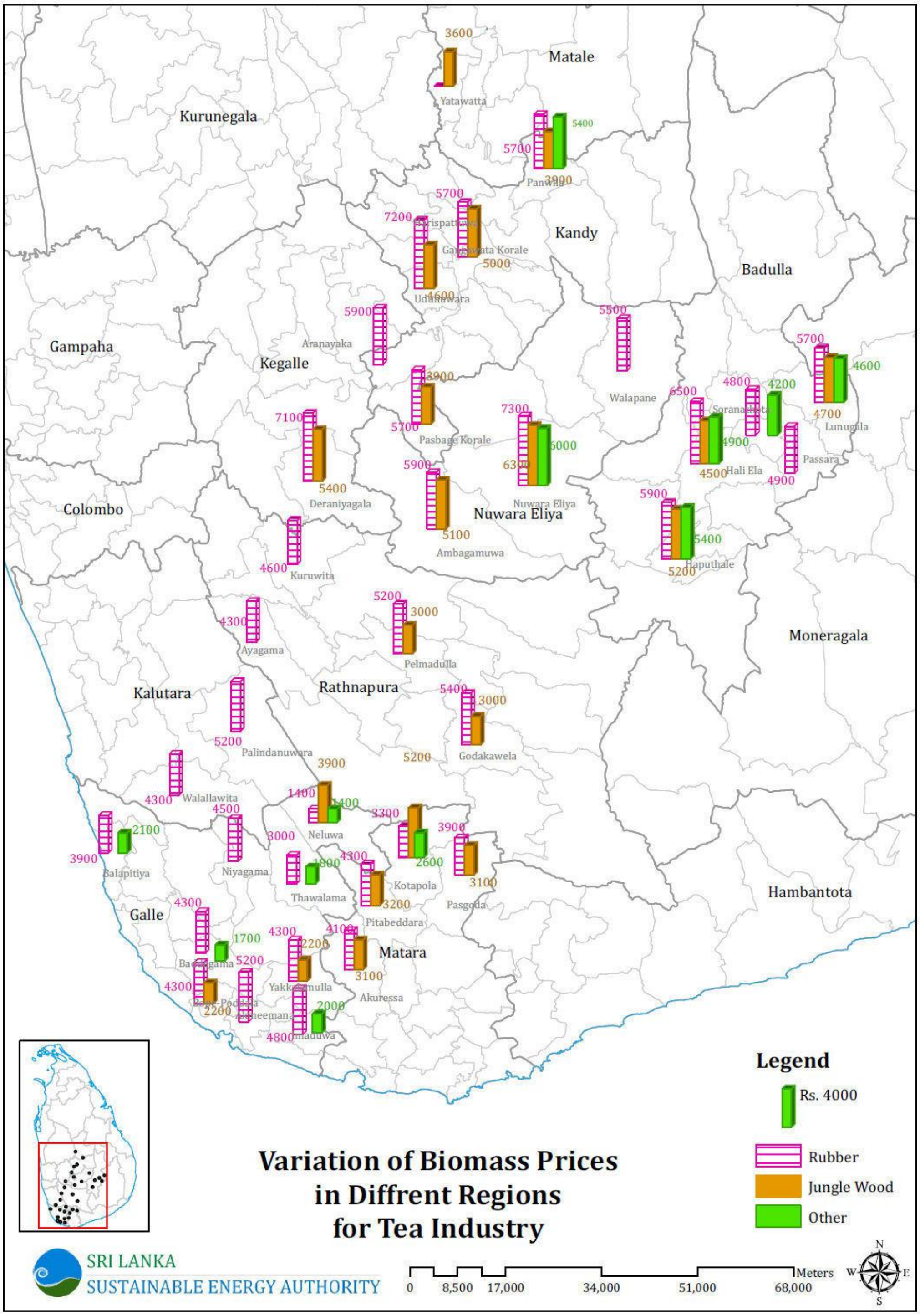

Figure 4: Variation of biomass price in different regions

When analysing the price, the average price of firewood was categorised under three categories, (as rubberwood, junglewood and other types) and the average value for each Divisional Secretariat was mapped. Note that in plantation companies owning both tea and rubber plantations, the fuel wood supply could come within the same plantation group at a cheaper price. According to the elaborations in the Figure 4, there are marked disparities according to the type of biomass and the location of tea factories. As an average, upcountry factories had to pay about LKR 6,800/MT whilst the low country factories managed to obtain firewood for about LKR 3,600/MT. Saw dust price was around LKR 3,250/MT for Sri Lanka.

Biomass Supply Areas for different regions in the country

When analysing the data obtained from tea factories on biomass supply, it was noticed that tea factories can be categorized into four consumption areas, having common characteristics. The observations are given in the table below. Refer Figure 5 for more elaborations.

Table 2: Details of biomass consumption areas and biomass supply areas

Consumption areas (Districts)	Details of biomass supply areas
1. Nuwara-eliya, Rathnapura, Kaluthara, Colombo	The biomass supply to these tea factories comes from highest distances among others. Also the largest amount of tea is produced in these areas, amounting to larger biomass consumption. These industries reported the highest issues in biomass cost, availability and reliability of supply. Another reason for their problems could be that their supply areas also provide biomass to other industries like bulk rubber, textile and BOI Zones, etc.
2. Kandy, Matale	Biomass supply areas are seen in the same district and the adjacent district. The supply areas also provide biomass to other industries like lime, brick, etc.
3. Badulla	Biomass supply areas are seen in the same district and the adjacent district. The same supply areas can provide biomass to Tea Factories in Nuwara-eliya District.
4. Galle, Matara	Biomass supply is usually supplied by the same District for most occasions or at most, the adjacent district.

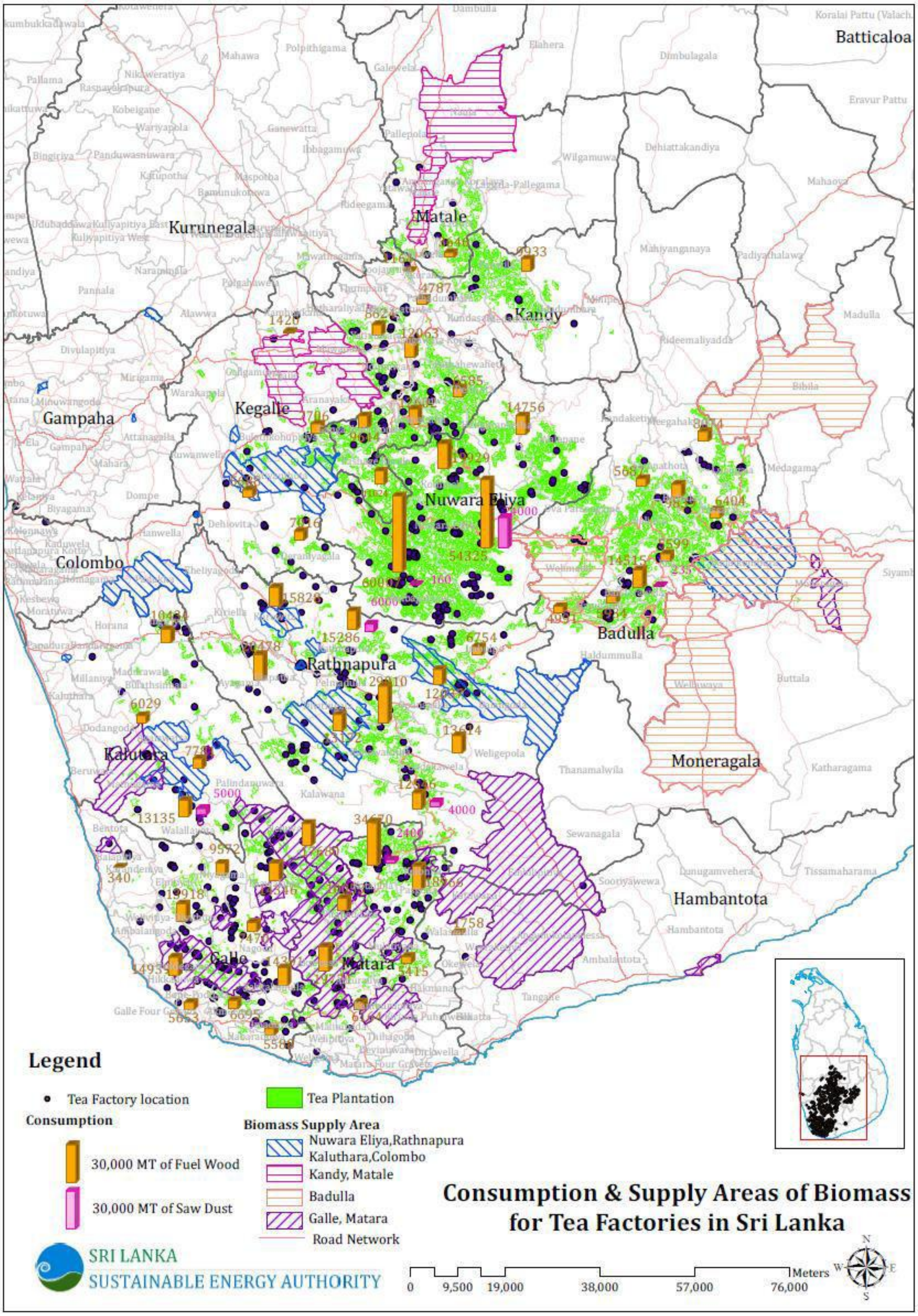

Figure 5: Supply areas of biomass price for different regions

Conclusion & Recommendations

Rising biomass costs is a serious concern in tea industry, and tea factories will be one of the main victims if the biomass supply is unstable and the price gets increased over the years. Apart from a few bulk industries, the highest average price of fuel wood is seen in upcountry tea factories among all industries.

Fuel wood usage is done in ad hock ways in certain factories. E.g. some fuel wood have high moisture content levels such as 40% before firing. This results in very high SFWC values. However, it should be commended that many industries have now understood the value of energy efficiency, and some factories have reduced the SFWC to a greater extent, even to about one third of the SLSEA baseline. Switching to alternative types of biomass like saw dust, briquettes, factory wastes and paddy husk has been started by a couple of tea factories as well.

Some tea estates in the corporate sector own uncultivated lands. According to a survey by TRI there are about 14,287 ha of uncultivated lands in the corporate sector tea estates of which 7,789 ha are at low elevations [4]. Promoting the cultivation of suitable fuel wood species in these lands should be done for the security of thermal energy in tea sector, and incentive mechanisms should be available for the industrialists.

Acknowledgements

The authors are especially thankful to Sri Lanka Tea Board, Tea Research Institute, tea factory officers and boiler manufacturers who provided information to this survey. The authors wish to thank the senior management of SLSEA, mentioning Dr. Thusitha Sugathapala, Mr. M.M.R. Pathmasiri, Mr. Sanath Kithsiri, Mr. Vimal Nadeera and Mr. Chamila Jayasekera for the immense support and guidance. The authors are grateful to Ms. Gayathri Jayapala, Mr. Vijitha Ekanayake, Mr. Gayan Subasinghe, Ms. Nimashi Fernando and the undergraduate trainees of University of Moratuwa & University of Sri Jayawardanapura in SLSEA for all the support given in data collection and Ms. Chamila Jayani Piyarathne for her contribution in data entry operations.

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**Individual factory production details were obtained from Sri Lanka Tea Board, and these data were analysed to DSD level and are presented in a way that individual factory details cannot be traced from a third party. Factory wise production data will not be published/revealed under any circumstances to any other party from SLSEA.*

GIS based model to identify potential sites for Mini hydro power projects & develop tool for capacity calculation

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Abstract

Realizing the maximum feasible capacities in small hydro power projects is very important and in this context finding a suitable location with suitable terrain (head), catchment, flow rate, and adequate rainfall is a fairly complicated task.

Although hydropower is the most established renewable resource for electricity generation in commercial investments, it is of great importance that this kind of renewable energy should be further developed and become more attractive to investors of the public or private sector.

This study presents a GIS methodology to perform a preliminary selection of suitable areas and feasible locations for installing small hydroelectric power plants integrating multi-criteria. As calculation of the installed capacity of a mini hydropower project is important an easy to use ArcGIS tool for hydropower capacity has also been developed in the study.

The ultimate result of the study is facilitating Sri Lanka Sustainable Energy Authority with regard to finding suitable areas for mini hydropower projects and calculation of capacity of the proposed projects.

Keywords: GIS, Weighted Overlay Model, Multi-criteria Analysis

Introduction

Site selection process for a mini-hydropower plant is a key challenge faced by the investors as well as the approving authorities. The new technologies such as Geographic Information Systems (GIS) could be utilized in this site selection process to a greater extent. GIS could be used as a decision support system in an administrative level because of its ability to compute several scenarios for hydropower development in hydrological basins.

Geographic Information system (GIS) is define as a special kind of information system that is used to input, store, retrieve, manipulate, analyze and output geographically referenced data or geo-spatial data, in order to support decision making. A GIS hold attributes with locations and enables users to perform geospatial analysis in addition to make attribute analysis. That often facilitates to explore the hidden spatial relationships of the real world objects.

The powerful capabilities in GIS such as overlay analysis, proximity analysis, multi-criteria analysis, 3D analysis, spatial analysis, attribute queries, and mapping techniques can be efficiently employed in relation to renewable energy projects.

GIS in Mini-Hydropower Projects

Hydro power converts the energy in flowing water into electricity. The quantity of electricity generated is determined by the volume of water flow and the size of the “head”. The “head” could be defined as the height from turbines in the power plant to the water surface. High head and the large water flow often generate more electricity through the turbine. Almost all the factors which influence on hydropower generation are geospatial in nature. Therefore, a computer system with geospatial data handling capabilities can be an ideal solution to analyze the mini-hydropower projects in many aspects. Hence, Geographic Information Systems which facilitates in geospatial data input, store, retrieve, manipulate, analyze and output could be used effectively in mini-hydropower projects as well as other renewable energy projects.

Development of hydro power project could be easier when a most suitable location is selected at the beginning by considering all the relevant factors. This task involves many spatial layers such as elevation, hydro network, rainfall, forest, wildlife habitats, land use etc. An overlay analysis of all these factors could define most suitable locations for new mini hydropower projects.

Also an accurate capacity calculation of a mini-hydropower plant is another problem. Mini-hydropower generate capacity calculation involves factors such as terrain, watershed, rainfall, infiltration, water flow etc. All these factors are spatial in nature. Therefore some spatial analysis techniques could be easily employed in precise capacity calculation of a mini hydropower plant.

The main objectives of this study are finding suitable locations for mini-hydropower projects; create a ArcGIS tool for power calculation.

Software and tools used

ArcGIS 10.1 software and its extensions such as 3D Analyst, Spatial Analyst, Data Interoperability were mainly used in the study. In addition, free extensions for ArcGIS such as ArcHydro 9 Tools, Hawth's Tools, X Tools, CN Runoff Tool and Watershed Delineation Tool were used time to time in the study.In addition to GIS software and tools MS Access, MS Excel also used for various attributes management and create graph etc.

Twelve Divisional Secretariat Divisions in Kalu Ganga river basin was selected as the study area in this project

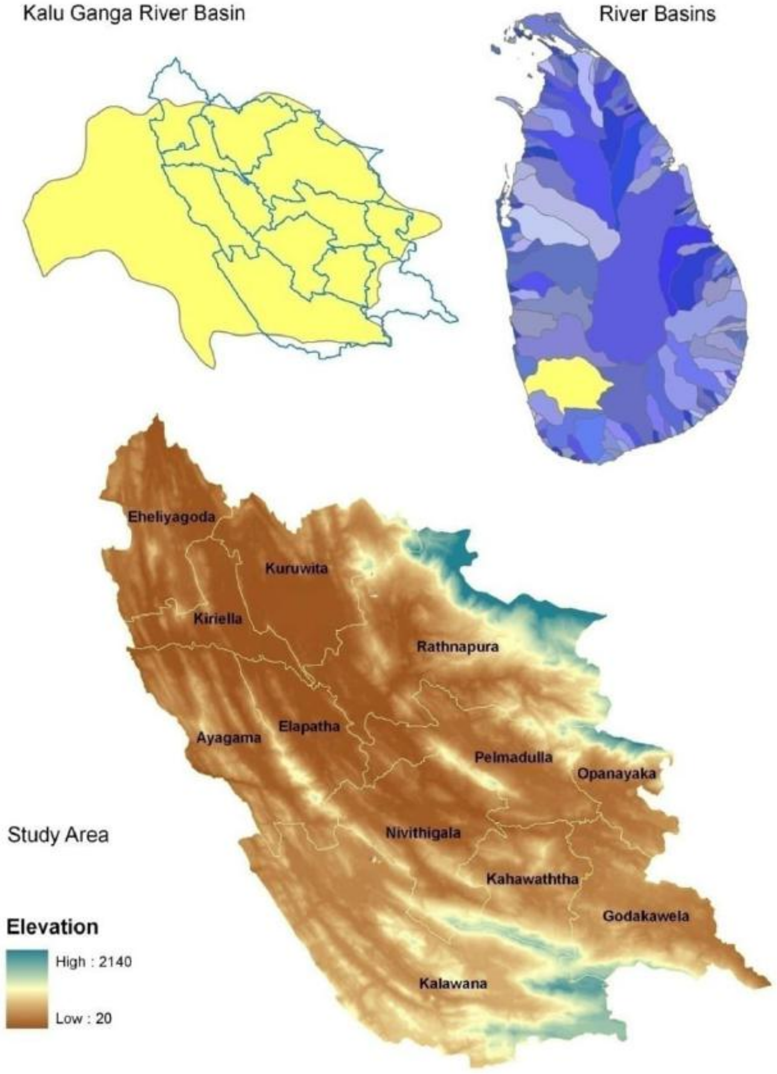

Figure 1: Map of the Study Area, Part of Kalu Ganga River basin

The analysis is comprised with three major sections.

1. Performing a multi-criteria analysis to identify the areas which offers a conducive environment to develop mini hydropower projects.
2. Establishing and validating a hydrological model suitable for the estimation of stream flows in river or tributary.
3. Developing an ArcGIS tool which facilitate the estimation of hydro electric power potential and energy yield on a given stream location.

Part 1: Weighted overlay model

Though the understanding and verification of technical aspects are essential for project design, there are many other factors which influence the project development process and investment decisions. The most prudent way to assess and quantify the influence from number of likely factors is to incorporate such variables in to multi-criteria weighted overlay model. In order to identify the most preferred areas for mini hydropower projects in a given river basin (Kalu Ganga river basin), a multi-criteria weighted overlay suitability model was created. The suitability is always depending on many geospatial factors. Therefore, eight (08) most influential geospatial factors were chosen. The most prominent factors which influence the project development decisions could be categorized as follows

1. Watershed
2. Rainfall
3. Land Use
4. Elevation / slope
5. Soil Pattern
6. Distance to Electricity Lines
7. Distance to Roads
8. SEA Declared Areas

Therefore it is evident that the selection process of a hydro electric power project site has many facets. First and foremost it is essential to establish that the site has a potential for power generation and secondly sites derived from that process need to be further screened in line with the influencing factors depicted above. Hence the entire project development process could be multi dimension in nature and as such our decision to employ a multi-criteria approach may be justified. It is important to note the desired outcome of multi-criteria approach; which involves a use of number of alternatives having many attributes. This act as a useful tool in analyzing alternatives and evaluate the same against their comparative advantages and disadvantages. The outcome of the multi-criteria analysis is the ranking of alternatives which in turn provide us the opportunity to compare between potential hydro electric power projects.

When an individual factor is considered, that can be classified in to several classes based on the values presented. For an example, rainfall layer can be classified into several classes based on the rainfall values. Then the classes can be assigned a weight base on the influence or the importance to the suitability for a mini hydropower project. For an example, for the places where rainfall is less, a lower weight can be assigned while rainfall value is large, higher weight can be assigned.

Another main purpose of assigning weights is to convert different units of values presented on the above factors in to a single unit. For an example, rainfall values are in millimeters and distances in kilometers while elevation in degrees. The assignment of weights converts all these values into a single unit such as 0 - 5 which 0 shows lower weight and 5 shows a higher weight.

Accordingly, the above individual factors were ranked into 05 classes' base on the suitability.

The value 5 was given for the areas where the considered factor is presented in most favorable manner for the hydropower projects while value 4, 3, 2 and 1 was given for the next suitability levels. Accordingly, the above selected spatial factors were assigned suitable values from 1 to 5 based on their attributes.

The value 5 was given for the areas where the considered factor is presented in most favorable manner for the hydropower projects while value 4, 3, 2 and 1 was given for the next suitability levels. Accordingly, the above selected spatial factors were assigned suitable values from 1 to 5 based on their attributes.

The watershed and rainfall are the main influencing factors for deciding a suitable location for a mini hydropower project. Therefore, two separated weighted overlay models were created with the purpose of precisely identifying the most suitable locations.

A. Water Flow Model - to identify the areas where having potential water flow (Watershed area and rainfall)
B. Weighted Model for other factors - to identify areas where favorable for a hydropower project.

Then, a composite map was created with above two weighted overlay models using Weighted Sum function.

Even though all factors are favorably presented, within some restricted areas such as wildlife conservation areas and forest reservations mini hydropower plants are strictly not allowed. Therefore, those areas were removed from the composite map to finally identify the developable areas.

A .The Water Flow Model

The water flow is one of the essential factors of deciding suitability of mini hydropower project. This evaluates the hydro potential or the capacity of a weir location of a mini hydropower plant. The water flow is often calculated by aggregating runoff of upstream catchment area and the rainfall availability to the catchment.

Rainfall

Rainfall is a major decisive factor for hydropower projects feasibility. The installed capacity for a power project is mainly depend on the amount of rainfall

falling to the catchment area. The rainfall values are collected using rainfall collection centers located all over the country. These values should be reasonably interpolated to
make a rainfall surface map. Since this rainfall map is a continues surface, it had to be re-classified to a define number of classes to scale factors. As described above, the highest suitable class was assigned 5 and least suitable class was assigned value 1. Assignment of scale factors on each class is shown in following table.

Table 1:Watershed Area classes

Watershed Area (no. of pixel)'000	Area (km^2)	Class	Value Assigned
176 – 800	4.4 – 8.0	1	1
800 –	8.0 – 16.0	2	2
1,600 –	16.0 – 24.0	3	3
2,400–	24.0 – 32.0	4	5
3200 –	32.0 – 40.0	5	5

Watershed Area

Upstream catchment area for a particular location also is a most important factor of deciding power or energy capacity of a mini hydropower project. Watershed areas for each stream link point were calculated using ArcGIS by assigning 40,000 as threshold value. Since the pixel size is 5 m, the watershed was calculated only for the locations where the area is greater than one square kilometer.

As described above, the highest suitable class was assigned 5 and least suitable class was assigned value 1. Assignment of scale factors on each class is shown in following table. The watershed areas were also classified into five classes as shown in following table with the purpose of assigning scale factors to be used in the overlay model.

Table 2:Rainfall value classes

Rainfall (mm)	Class	Value Assigned
195 – 240	1	2
240 – 285	2	3
285 – 330	3	4
330 – 375	4	5
375 – 420	5	5

When considering the above two factors, rainfall is the most crucial factor because, less rainfall will minimize the capacity although it has a large watershed area. Therefore, the rainfall was weighted by 65% for rainfall and 35% for watershed area. The weighted overlay model created in ArcGIS on the watershed and the rainfall value map. The weighted overlay map shown in figure illustrates the water flow levels in the study area which highly influence on the capacity of a mini hydropower project

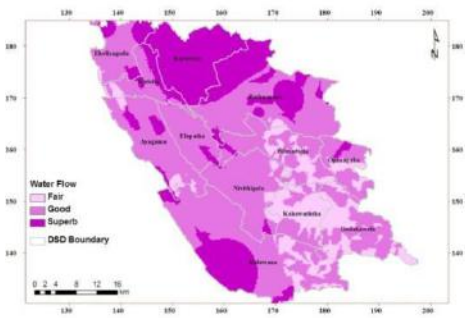

Figure 2: Weighted Overlay Water Flow

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B. Weighted Overlay Model for Other Factors

In addition to water flow, there are many facts which influence on the suitability of a mini hydropower project. As mentioned before land use, soil type, slope, distance to electricity grid substation and distance to access roads are main decisive factors.

a) Land Use (LU)

The existing land uses also one of the major factors of deciding suitability for mini hydropower projects. Values were assigned for land use classes considering their properties to retain water without evaporating. Therefore, the area covered with forest was assigned 5 as the scale factor other land uses also assigned relevant scale factors based on the characteristics.

b) Slope (SL)

The rate of change of the surface in the horizontal and vertical directions from the center of a cell determines the slope. Slope is a crucial factor in determining the suitability for hydropower projects. This decides the 'head' of the water flow drop on to the turbine in the power generation process. Therefore generally accepted, at least 30% slope should be presented for a hydropower projects. Slope map was generated using 5 m pixel elevation surface

c) Soil Type (SO)

The soil type also one of the major factors of deciding suitability of mini hydropower projects. Soil type often influence on the hydropower projects in many ways including infiltration, stability etc.

d) Distance to Grid Sub Stations (DG)

The ultimate objective of a mini hydropower project is to connect the generated electricity into the national electricity grid. Most of the parts in study area presence with the national electricity distribution lines, but distance to a power stations is a major consideration, because of the generated power can be linked to the national grid only through a power station. For this purpose, a distance raster was created to calculate the distance from each power station using Straight Line Distance tool in ArcGIS. That calculates the distance for each cell, the least accumulative cost distance to the nearest source, while accounting for surface distance and horizontal and vertical cost factors.

e) Distance to Roads (DR)

Easy accessibility to the project site is also a significant factor because of the transporting materials and other stuffs is compulsory requirement in the construction period. This requires a sufficient access road to the site. On the other hand, constructing a new road is a costly and time consuming option and often very difficult. In this analysis, major roads, secondary roads and track roads were considered since the foot paths are not be used to transport motor vehicles. Straight line distance method was used to calculate distance to roads. Here, the analysis was performed even beyond study area with the purpose to consider the nearest roads outside the study area boundary. Then it was extracted by study area layer.

f) Energy Development Area(ENR)

SLSEA has declared some areas as energy development area to easily solve the conflicts with regard to the land ownership of projects. Within this declared areas, SLSEA is involving in land acquisition, purchasing or leasing process with the powers vested to them. Therefore, project sites located within the declared areas having additional benefit to carry out the work with minimal problems in land acquisition.

Assigning Weights on the Factors

In the weighted overlay model, all the above factors were weighted based on the significance of each factor on deciding suitability for mini hydropower projects. All the factors are always not equally important, one factor may be highly important in the analysis while some other factor may not that much important. Therefore, assigning weights on each layer based on the significance is improving the precision of the result. However, deciding the significance of each factor is quite difficult because there is no measurement to determine the significance. Therefore, related literature on previous studies and informal discussions held with professionals were the base for the comparative significant value for each factor with other factors.

The relative importance of each criterion was evaluated against other criteria. As a example, if Land Use (LU) is considered to be 10 times more important than Energy Development Area (ENR), then 10 is recorded as ENR/LU and 0.1 is recorded for LU/ENR.

Table 3: Pair Wise Comparison Matrix of Criteria

	LU	SL	SO	DG	DR	ENR
LU	1	1.25	1.33	1.66	2.5	10
SL	0.4	1	1.25	1.43	1.66	10
SO	0.4	0.8	1	1.33	2.85	10
DG	0.3	0.7	0.75	1	2	5
DR	0.3	0.6	0.35	0.5	1	5
ENR	0.1	0.1	0.1	0.2	0.2	1
Total	**1.9**	**4.45**	**4.78**	**6.12**	**10.21**	**41**

According to above Pair Wise Comparison Matrix, weighted values were calculated as shown in the table.

Table4: Analytical Hierarchy Process of Criteria

	LU	SL	SO	DG	DR	ENR	Sum	Avg/ Weight
LU	0.21	0.27	0.28	0.28	0.24	0.24	1.53	**25.54%**
SL	0.21	0.22	0.22	0.26	0.16	0.24	1.32	**22.04%**
SO	0.21	0.21	0.18	0.21	0.28	0.24	1.33	**22.13%**
DG	0.16	0.16	0.16	0.16	0.20	0.12	0.95	**15.91%**
DR	0.16	0.11	0.13	0.07	0.10	0.12	0.70	**11.59%**
ENR	0.05	0.03	0.02	0.02	0.02	0.02	0.17	**2.79%**
Total	**1**	**1**	**1**	**1**	**1**	**1**	**6**	**100.00%**

Finally, all the above factors had to be combined and prepare a composite map to evaluate the suitability for hydropower projects. Overlay analysis is one of the most useful methods in GIS in multi-criteria or multiple layers based analysis. Weighted Raster Overlay method in ArcGIS was used in this task.

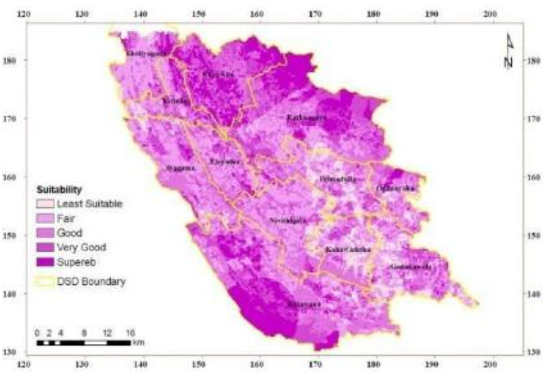


Figure 3: Weighted Overlay Map of the Considered Factors

The above figure shows the weighted overlay map created with the model. The result was categorized in to five categories and labeled as Superb, Very Good, Good, Fair and Least Suitable based on the degree of suitability.

Weighted Sum Analysis

Water Flow is the main decisive factor of locating a mini hydropower project. This has been already calculated for the study area using the Water Flow model. Also, other important factors were taken in to account in the weighted overlay model. Finally, to identify the most suitable locations for mini hydropower projects, the sum of above two overlay models were taken. It was calculated by Weighted Sum function in ArcGIS Spatial Analyst. As mentioned above, the water flow is more significance in the suitability analysis. Therefore, 65% was assigned on water flow layer and 35% assigned on the other layer to obtain the weighted sum. Following shows the final weighted sum map.

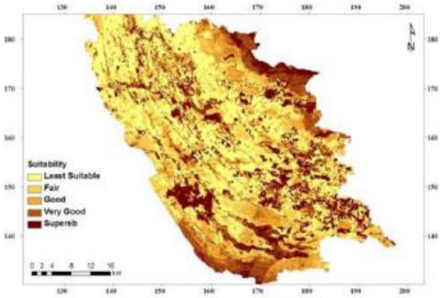


Figure 4: Weighted Sum Suitability Analysis

Composite Suitable Area for MHP

Areas declared by various government gazettes and ordinances as environmental sensitive areas or protected areas considered as excluded areas. Although, all other factors are presented favorably for a hydropower project, it is not possible to start any development or within these sensitive areas. In Sri Lanka forest reservations, wildlife conservation areas are mainly considered as excluded areas.

The suitability map was erased by this excluded areas map in order to identify the developable areas. Finally, the existing already grid connected (commissioned) hydropower projects were overlapped on the suitability map. The map clearly shows that the most suitable areas are already covered with the commissioned projects.

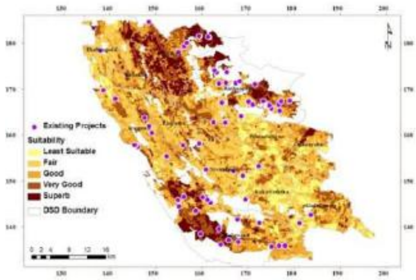


Figure5: Compare Composite Suitability Result with Existing Commissioned Projects.

Part 2: Hydrological analysis

Weighted Overlay Model was developed to identify suitable areas for mini hydropower projects by analyzing the relevant factors with their significance. Finding potential sites (locations) for mini hydropower projects is another objective of the study. This was achieved by doing a hydrological analysis. The steps followed in this analysis are as follows.

- Identification of sites in the study area having suitable elevation.
- Calculation of available flow of water at the selected sites.
  - ✓ Calculation of catchment area for sites.
  - ✓ Calculation of runoff values
  - ✓ Calculation of available water flow
- Calculation of generating capacity.

It was decided to consider the locations having an at least 1 square kilometer catchment in this analysis. Therefore, in order to identify watersheds with less than 1 square kilometer, watershed analysis was performed for corrected DEM by watershed delineation tool in ArcGIS and assigned 40,000 as threshold value for analysis. 40,000 means minimum number of downstream cells was considered for analysis. Since, cell size of DEM is 5 m, to have 1 square kilometers 40,000 cells must be there. The created watershed raster then converted in to a vector a polygon layer and streams within more than 1 square kilometer catchments were extracted.

Identification of Sites Having Suitable Elevation.

If there is a good catchment area, even 10 meter elevation could be sufficient to locate a hydropower project. Therefore, every point having 10 meter elevation deference was selected for the hydrology analysis by creating points where intersect stream with 10 m elevation contours. 543 points were created with unique ID number and then calculated X, Y coordinates and linear distance along the river for each point.

When selecting feasible sites for hydropower projects linear distance also important factor because long distance for small capacity may not be feasible since the financial cost and other social and environmental cost may be higher. To calculate distance along the river, river line layer was divided by point layer and calculated the length of each river segment. Then the point layer and river layer were joined together to get distance values to points attribute table.

Calculation for Catchment Area

ArcHydro tools was used for watershed analysis in hydrology model in the study. Here, the catchment areas could be defined as a unique upstream cells for a particular point while watershed area consist all or cumulative upstream cells for a particular location of a stream.

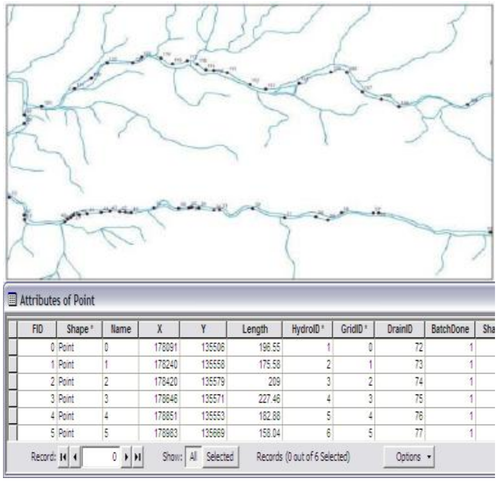
Catchments were calculated for all input points by using flow direction raster layer which was created from accurate DEM and point raster layer.

Output was in grid format and had been created attribute fields as GridID and HydroID when it was processing. Then it was converted as catchment polygons from "Catchment Polygon Processing" tool in ArcHydro tools.

It was essential to convert from ArcHydro tools because DrainID and BatchDone attribute fields are creating automatically when it is processing."Batch Watershed Delineation for Polygons" tool located in watershed processing menu was used for creating watershed for all input catchment polygons.

It will create an attribute field called HydroID when it is processing. In order to get related watershed area for input points all the tables was joined by their common attributes fields.

Finally, watershed area, X Y coordinates for all input points and distance between consecutive two points were in one attribute table.



FID	Shape *	Name	X	Y	Length	HydroID *	GridID *	DrainID	BatchDone	Sha
0	Point	0	178091	135506	196.55	1	0	72	1	
1	Point	1	178240	135558	175.58	2	1	73	1	
2	Point	2	178420	135579	209	3	2	74	1	
3	Point	3	178646	135571	227.46	4	3	75	1	
4	Point	4	178851	135553	182.88	5	4	76	1	
5	Point	5	178983	135669	158.04	6	5	77	1	

Figure6: Illustration of Attribute Table for Point with All Information and Related Map

Spatial Index Model

Out of 543 points 78 sites were selected as probable sites after excluding reservation areas. When selecting those sites some several points were taken as a single site. As an example, every point had 10 m elevation deference and selects 5 consecutive points as single site, then it has 50 m head and catchment area belongs to highest point.
A Spatial Index was created for selected points by assigning weights to their physical characteristics such as Land Use, Soil type, Distance to Grid, and Rainfall. This process followed 4 steps.

1. Identifying sub category and their scale of each factor
2. Assigned scale values of each factor to all selected locations (78 locations) by considering their physical characteristics.
3. All values given in above table were multiplied by related scale factor and weight coefficient and total values were calculated
(following figure shows the part of output).

Table 5: Part of the final output of potential sites

No	Name	Luse	RF	Soil	Grid	Total
1	23	0.22	0.28	0.1	0.12	0.74
2	37	0.3	0.21	0.1	0.12	0.7
3	57	0.3	0.17	0.2	0.15	0.82
4	89	0.13	0.35	0.2	0.15	0.83

4. If total value of above table greater than 0.75, could be assumed that at least 75% potential have to present all factors. Therefore, locations where total value greater than 0.75 was selected. 32 sites were identified as potential sites.

PART 3: POWER CAPACITY TOOL

Power Calculation Tool was created using ArcGIS Model Builder capability to enhance the efficiency of power calculation. Marking weir location on river by editing point layer and assign head measurement value, and design flow of the project, it will calculate the catchment area, installed capacity and monthly power capacity values.
Main input parameters for the tool are flow direction, flow accumulation, rainfall layers and head measurement value, design flow (optional). Output is the polygon shapefile.

Process in Tool

1. Input point shape file with unique ID field (short Integer).
2. Snap pour point will be created from input point shape file and flow accumulation raster layer. It will be snapped with a 10m tolerance to the flow accumulation layer.
3. Catchment grid will be created from snap pour point raster point and flow direction raster layer.
4. Catchment grid will be converted to polygon shape file.
5. New data field will be added to the catchment shape file and calculated area (km^2).
6. Catchment polygon layer will be spatially joined with input polygon layer rainfall value (with monthly average rainfall values for each month) will join to the catchment polygon layer (if there are few polygon rainfall features average value of each will be calculated).
7. 12 fields will be added to the catchment polygon layer and will be calculated power for each month using following formula.

   P = (rainfall*Area*1000000/(30*24*3600))*Head*9.81*.8
8. New field will be added to calculate Install capacity of the project and it will be calculated as follows.

   Capacity = Design Flow* Head * 9.81*.8

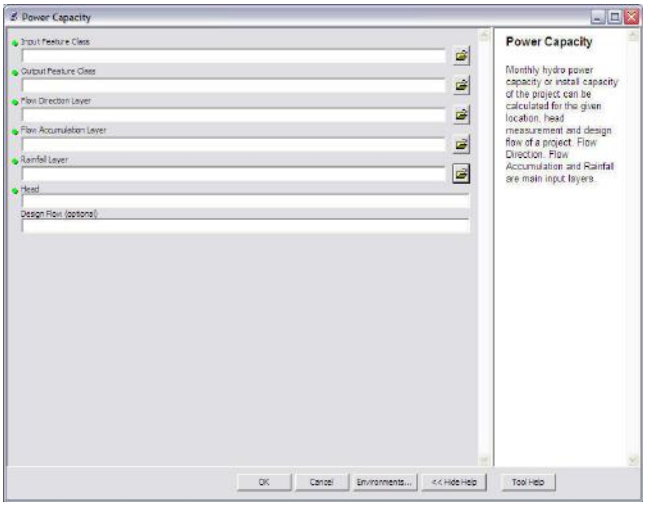


Figure 8: Illustration of Power capacity tool

Conclusions

GIS is an important tool for Mapping, Analysis, and Visualization of spatial data. Its special capability for multi criteria analysis was very useful in developing the model discussed in this research. Furthermore, analysis tools such as 3D Analysis, Proximity Analysis, Hydrology Analysis were extensively used in this study.

The findings (preferred areas generated by the model) of this research were compared with the operational power plants for site suitability. The most of the preferred areas depicted by the model shows that they are in close agreement with the already setup power projects. It is important to note that the final site selection for any given hydro power project is normally done after scrutinizing the project site for number of factors which are within the range of factors described in the multi-criteria analysis. During the design stages of these operational projects, the relevant studies and investigations for site suitability had been performed through site specific assessments. As such it is possible to endorse the research findings since the same are in close agreement with the already established project sites.

The GIS model developed in this research is very cost effective and quicker than the traditional approach of identifying potential project sites for small scale hydroelectric power projects. One of the salient features of this research is the fact that majority of the work can be completed by a desk study. Accordingly, valuable time and resources, which otherwise would have committed for field assessment work were saved. One of the striking feature of this model is that its capability to identify large number of potential hydro electric power projects within a, relatively, short period of time span.

Through the model developed by this research, it is possible to gain valuable insight to essential project information pertaining hydro electric power project. Also assessment of a potential project capacities and energy yield estimates of a project site can be performed with ease having an accuracy level expected at pre-feasibility level study. Hence research findings provide very valuable information for the potential project developers who need dependable project information prior to the commitment of funds for initial project development.

The model developed in this research is very flexible and has the facility to build and expand further to accommodate more information layers pertaining to all aspects of planning and development of hydro resources. It could be a deployment of an irrigation scheme or a diversion of water for a drinking water project or planning for a major development project, which require large amount of water, such as an Industrial Park in close proximity to the river basin. The model developed in this research has the flexibility to integrate all such factors and there by transforming the same towards a complete hydro resource assessment tool. Due to time and resource constraints, it was not possible to utilize all the data available for the study area. However, judging by the findings, this research can be considered as the first step towards hydro resource planning for small scale hydro electric power development.

Recommendations

Recommendation 1

The economic and financial viability of hydro electric power project is essential for policy makers as well as for potential project developers to decide whether the potential power project should be considered for implementation. Hence it is recommended to strengthen the GIS model develop in this research by taking in to account the key cost parameters and introduce a project specific cost which denotes the approximate investment per kW off installed capacity.

Recommendation 2

It is possible to further strengthen the hydrology model developed in this research by using more rainfall and flow data and conducting validation tests with a view to develop runoff coefficients accurately. One of the key areas to be investigated in future studies is to develop sub catchment runoff coefficients instead of a single runoff value for a larger river basin. This is very crucial when a river basin spread across a different climatic zones and comprise of different land uses and soil properties. Such an attempt would improve the accuracy of hydrology estimates and thereby improve the estimation of project capacities and energy yield estimates.

Recommendations 3

It is proposed to use more accurate data collected during short time spans such as daily data for rainfall and stream flows. The use of monthly average values gives a distorted picture about the rainfall and flow patterns. In fact averaging will underestimate the high flows and over estimates the low flow situations. It is essential to note that the hydro power project types depicted in this research are run of the river type plants. This means that the operation of the power plant is solely depend upon the flow available at the stream at any given time. Hence by using data taken at short time spans would enable us to capture the situation which is very closer to the reality.

Recommendations 4

In estimating the energy yield we assumed that the performance of the power plant (hydro turbine) to be linearly vary with different flow values. However in reality hydro turbines performs inefficiently during low flow situations when compared to its operation at rated flow condition and exhibits an almost non-linear behavior throughout its performance range. As such energy yield estimates calculated in this model will not be accurate and would carry some error. Hence it is recommended to use the actual power performance curves of the turbine for the calculation of expected energy yield.

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Colour as a Tool to Manipulate Indoor Thermal Perception in Cold Climatic Regions: A Field Experiment Implemented in Sri Lanka

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Abstract

As an alternative hybrid remedy for energy conservation in cold climatic regions, integrating warm colours in interiors was hypothesised to help the inhabitants to perceive the indoor thermal environment as warmer than the actual condition, compensating the heating costs to some extent.

A preliminary field experiment was executed to investigate the impact of a warm colour (red - Cranberry Zing) and a cool colour (Duck egg blue) on indoor thermal perception in a cold climatic region. Substantiating the hypothesis, participants consistently perceived red room to be warmer (90% - warm and 10% - slightly warm) while blue room was perceived to be even cooler 93.5% (64.5% - cool/ 29% - slightly cool) and 6.5% remained neutral.

Red colour was found to induce a warmer thermal perception against the actual cold thermal condition. Testing the same principle with interiors where a heating system is involved is highly recommended to identify the potentials of energy conservation.

Key words: Thermal perception, Warm colours, Cool colours, Cold climatic region, Energy conservation

Background

This is an era where innovative architectural and design interventions that focus on energy conservation, have been given a greater emphasis more than ever before. Amidst the diverse attempts made in innovative architectural planning and interior design solutions aiming at cutting down heating and cooling costs starting from the orientation of the building itself to the use of passive solar design strategies, construction methods and integrating appropriate building materials and finishes, the current investigation looks in to a simple, low cost potential solution; the use of colour as a hybrid method of energy conservation.

Colours are known to play many roles in the paradigms of Architecture and Design. As the prime and foremost role, colours have been widely used for aesthetic and visual purposes in built environment; to come up with an aesthetically pleasing harmonious composition. Further, integrating the ability of colour to alter the perceived dimensions of space and objects; length, width, height, depth, scale, proportion, weight and stability, has been a usual practice. However, colours are explained by the scholars, researchers and color therapists to influence thoughts, feelings, emotions and behavior; psychophysiological reactions, which in turn has been an evolving usage of colour beyond its typical aesthetic value, to aid human performance corresponding to the intended activity of built spaces. Amongst diverse colour associations, the current study focuses on the ability of colour to alter human thermal perception as a means of energy conservation.

At this juncture it is vital to clarify that the study does not focus on the heat absorbing / heat reflecting properties of colour which is already used as a strategy to conserve energy. As per the principles of colour theory, light colours will reflect more heat and dark colours will absorb more heat, thus lighter the colour the higher the reflectivity of a surface will be. Accordingly, while white has the highest light reflectance value (LRV), black is known as the best absorbent. For instance, white reflects 80% of the light, whereas black will reflect only 5%. This principle has been applied to manipulate and conserve energy to be spent on interior lighting. For instance, the higher the LRV number of the paint colour, the less artificial light will be needed (Morton, 2012). To be explicit, far more lighting is required for rooms with dark walls than those with light walls where the cost of energy involved is high. In addition to the walls, keeping the ceiling light and bright will increase reflectance to support energy conservation. Similarly, light colours applied on roofs are said to cut down cooling costs of interiors. Morton (2012) reports on a study conducted in Austin, Texas on a clear sunny day having an outdoor temperature of 90^oF (32.2^oC), where a white roof had a temperature of 110^oF (43.3^oC), an aluminum coated roof, 140^oF (60^oC), while a black, single ply roof, a temperature of almost 190^oF (87.8^oC). As further highlighted by Morton (2012) another study in Florida revealed that by increasing heat reflectivity, homeowners saved an average of 23% of their cooling costs. Accordingly LRV value of a coloured surface has been established as a decisive factor for energy conservation. The current study focuses on a different aspect of colour potentially conducive for energy conservation which is barely considered so far; the ability of colours to alter perceived temperature of human beings.

Supportive Literature

Figure 1: Warm cool division in the Colour Wheel

Colour can be identified in temperature terms (Mahnke, 1996). As explained by Candas and Dufour, (2005), thermal perception could be impacted by the visual appearance or the colour of an object. Moseley and Arntz (2007) explain that, colours have the power to endorse an implicit meaningful association in relation to temperature; typically, red is linked to “hot” while blue to “cold”.

Traditional colour theory distinctively differentiates between warm colours and cool colours to have opposite psychophysiological impacts upon humans. Colours red, orange and yellow are identified as warm colours which are stimulating, while blue, green and purple are explained as cool colours having a pacifying effect on human beings (Stone 2001, Ballast 2002).

Compared to the research conducted on diverse colour associations, scientifically or statistically substantiated research data on the nature of colour-associated thermal perception is scarce and inconclusive. In his book “Colour environment and human response”, Mahnke (1996) explains the warm/cool perception of colour as a synesthetic response; the unity between two different sensory modalities. This simply suggests that every sense is linked with each other. Moreover, he explains that colour perception is simultaneously linked with other perception modalities; perception of weight, volume and size, temperature, noise and sound, etc. As suggested by Mahnke (1996), colour has the power to suggest warmth or coolness as a manifestation of a synesthetic response.

On the other hand, though not proven scientifically, principles of colour therapy, a method of healing ailments with the use of colour energy, explains the possibility of colour to alter human body temperature as a metaphysical reaction which is a potential reason for the perception of certain colours as warm and vice versa. For instance, while Manuel (2011) suggests that, colour red can increase one’s energy level and raise the body temperature, Lung (2011) proposes colour blue to lower the pulse rate and decrease body temperature. In a recent study, Hettiarachchi (2014) investigated on the logic behind manifestation of colour-associated thermal perception with reference to red and blue colours in a controlled laboratory environment (26^{o}C/ 50% rh /350 lux) testing three hypothetical sub questions; the possibility of thermal perception triggered by colour stimuli to be an actual thermal sensation, a biological response (alteration in core body temperature) or a psychological response. The psychological parameters were statistically significant against the parameters of actual thermal sensation and core body temperature. Accordingly, this study statistically established the thermal perception associated with colour to be a psychological response. No matter how this warm/cool duality of perception is surfacing, as mentioned by Mahnke (1996), people are found to be fairly unanimous in their opinion of colours that visually induce either effect.

Researchers who have attempted to provide scientific evidence to the traditional theory of warm and cool colours are minimal. Mahnke (1996), the president of international colour association, has cited a few previous researchers who have provided supportive evidence for the perception of colour in temperature terms. A study done by Johns Itten (1961 cited in Mahnke,1996) demonstrated a difference of 5-7 in the subjective feeling of hot or cold between a workroom painted blue-green and one painted red-orange. Occupants of the blue-green room felt that 59^{o}F as cold, whereas the temperature had to fall to 52^{o}F in the red-orange room before the subjects felt cold. Clerk (1975) reported on the employees who complained of the cold in an air-conditioned factory cafeteria with light-blue walls, although the thermostat was set at 75^{o}F. The walls were repainted orange and the 75^{o}F temperature setting was set, then considered too warm, was reduced to 72^{o}F. In a Norwegian study, subjects tended to set the thermostat 4^{o} higher in a blue room than in a red room (Tom and Micelles, 1976). Further strengthening this ideology, Morton (2012) reports on tests which people estimate the temperature of a room with cool colours, such as blue and green, to be 6-10^{0}F cooler than the actual temperature. Warm colours, such as red and orange, will result in a 6-10^{0}F warmer estimate. Accordingly a few scholars have yielded supportive evidence for the ability of colours to alter thermal perception of an interior.

However, as identified by Gage (1995), the usage habits of colour associated temperature in prescribing colours have always been a matter of debate and puzzlement. The lack of knowledge on the nature of manifestation and the contributing factors of colour associated thermal perception are the main causes that obstruct its effective integration in man-made environment.

Going in line with the a few supportive findings, the current study attempts to seek the possibility of integrating colour as a tool to conserve energy in the cold climatic region. A recent investigation executed by Hettiarachchi (2014), revealing this association to be a psychology/ical reaction, firmly suggested the potential of the warm cool dichotomy of colour perception to be integrated in the built environment to 'psychologically manipulate the occupant's perceived thermal milieu against the actual thermal conditions', which could eventually contribute as an alternative remedy for energy conservation. Consequently, the research design of the current investigation was formulated considering that the perception of warm/cool colours is a psychological reaction.

Building interiors are always designed integrating warm colours as a traditional practice of British culture, being molded and fashioned amid a cold climatic condition. In fact the inhabitants of Britain by default demand warm colours in their interiors and reject cool colours (Perera, K, personal communication, July 8, 2014). Even though not established in literature, this provides inspiration for an unconscious psychological response accumulated via the course of time and converted in to a practice to counteract the cold climatic conditions using the perceived thermal aspect of colour where a psychological thermal comfort is achieved. As mentioned by (Mateeva, 2011), it may be expected that people with long-lasting adaptation to hot climates have lower sensitivity to them and higher sensitivity to cold climates, and vice versa – people durably adapted to cold climates have lower sensitivity to them and higher sensitivity to warm climatic conditions. Accordingly, it can be proposed that the inhabitants of cool climatic regions could prefer stimulating, warm psychological impact of warm colours against the cool, pacifying impact of cool colours thus could be very sensitive, responsive to warm colours against cool colours and will be benefitted by the same.

To highlight a parallel approach, Albers et al (2013) attempted to test colour in the form of light; warm/cool coloured LED lighting scenarios to conserve energy in aircraft/aviation industry. Subjects reported slightly warmer thermal sensations in yellow light and slightly colder sensations in blue light resulting in a slightly higher satisfaction with the (whole) climate situation in yellow light within the aircraft interior. As revealed by Albers et al (2013), even though the impact of lighting on temperature and comfort sensation is minimal, when utilized in a large-scale could potentially contribute to a quantifiable impact on energy savings. Similar impacts could be anticipated by the integration of colour in the applied form (paints/pigments). Supportively, Morton (2012) has suggested that "Colour does play an important role in energy conservation".

Hypothesis

The current study hypothesized that warm colours (red) integrated in an interior of a cold climatic region will make the inhabitants perceive the interior as warmer than the actual thermal condition while cool colours (blue) in the same interior will make them feel even cooler.

Aims and objectives

This research attempted to test the above hypothesis related to a real life situation via a field investigation. The findings of the study can be helpful on one hand to architects, interior designers, and landscape designers, who are interested in the avenues of improving thermal comfort of interiors in cold climatic environments. On the other hand, this will further provide insight to recognize colour as another factor which should be considered in the process of formulating energy efficient design strategies. For instance it is expected here that warmer thermal perception psychologically induced by a warm colour in an interior of a cold climatic region can compensate the energy to be spent on heating the interior to some extent; a hybrid remedy for energy conservation.

Method

Personalized houses possess the most familiar spaces of human beings, to which they are highly sensitive than any other space in the built environment. Therefore, the simplest alteration done in one's own home may have a greater impact on his/her perceptions and resulted psychophysiological responses. An alteration in one's bed room which is the most personal space may have a predictable impact on its user in this regard. Accordingly, the design of the current field investigation was focused on altering the colours of bedrooms to test the impact on thermal perception. In order to represent the cold climatic condition Talawakelle, a town located in Nuwara Eliya district of the central Province was selected (mean annual temperature -18°C).

Figure 2: Location of selected houses -Google map – Upper Kothmale hydropower project Housing scheme

Figure 3: View - Upper kothmale hydropower project Housing scheme

Research Design

Figure 4: View of a sample house

A sample of 7 nos of identical houses from a housing scheme having the same plan and identical method of construction, materials and finishes constructed under the upper Kothmale hydropower project were selected to execute this field investigation. Being adjoining houses located in the same locality all the climatic factors; solar radiation, outdoor temperature, humidity and air velocity pattern remained same. In these selected seven houses there were 31 participants of varying age groups representing both genders (17 males and 14 females). Two identical bedrooms having the same dimensions, and fenestrations (a door and a window in each) were selected to apply the colour. The colours to be tested were proposed to be applied on an identical wall per room; a warm colour on one wall and a cool colour on the other (Figure: 5) while the other three walls were proposed to be painted in brilliant white (Figure: 7, 8, 9). This decision ensured that the two rooms to be tested are identical in every aspect other than the introduced red or blue colour.

Colour Selection and application

A red hue was proposed to be tested as the warm colour based on the stimulating effect of the colour identified in theory of colour. Even though red in its full intensity will induce the greatest impact, considering the ethical fact that this colour is to be applied in a house occupied by human beings, and the new colour scheme is proposed to be remained unchanged until the next colour wash to be done by the occupant, a de-intensified version of red (Cranberry Zing) was specified. On the other hand, being the most recognized colour representing the cool paradigm of the colour wheel, a blue hue was proposed to be tested. Considering the accepted cooling and sedating effect of the colour found in colour theory, despite using blue hue in its full intensity a de-intensified version of blue was selected from the colour manufacturer (Duck Egg Blue). The specified colours were shown to the respective house owners and their consent was obtained prior to the application, fulfilling ethical concerns.

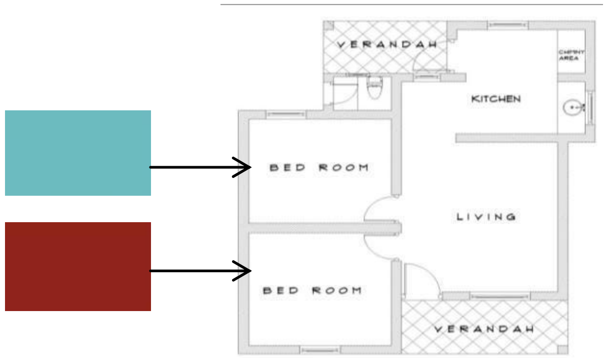

Figure 5: Layout of a house

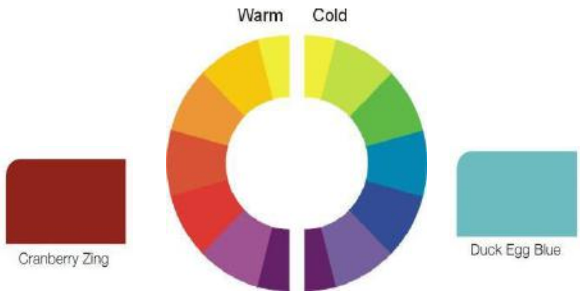

Figure 6: Colours specified to represent the warm and cool paradigms of the colour wheel

Figure 7: Canberry Zing, brilliant white and duck egg blue before application.

Precise instructions on the colour

Figure 8: Colour application process ss were provided to the

house owners, and all the seven houses were coloured simultaneously with their involvement under the supervision of the investigator. This can be identified as a win-win situation where these seven houses were painted free of charge.

Figure 9: 3D view of the identical bedrooms after colour application

Data collection

At the onset of the investigation, favorite colour/colours of the participants of each house were inquired to test the possible impact of long term exposure to a cold climatic condition on colour preference. It was expected here that, residents in a cool climatic region might prefer warm colours against cool colours due to its perceived warm thermal impacts.

Once the new colour scheme was applied, the subjects were requested to occupy the rooms for 24 hours to follow their normal routine while getting exposed to the new colour scheme. Following the new colour exposure, the subjects were interviewed to identify their general response; attitude, feelings emotions towards the new scheme and the effect of red/blue colours on their thermal perception of the interior.

The main data collected was the possible difference of thermal perception of subjects associated with new colour scheme with reference to the two bedrooms; red room and blue room. The subjective perceptions were transformed into objective data with the use of a 5 point likert scale which is a reduced version of the PMV scale (Fanger, 1970).

Figure 10: Likert- scale questions
Source: PMV scale (Fanger, 1970)

Results and Discussion

Research findings revealed by the questionnaire are graphically presented below.

Favourite colour

Question answered: What is your favorite colour? (Blue, Red, Green, Yellow, Purple, pink, white, black…………) Other suggestions if any…………

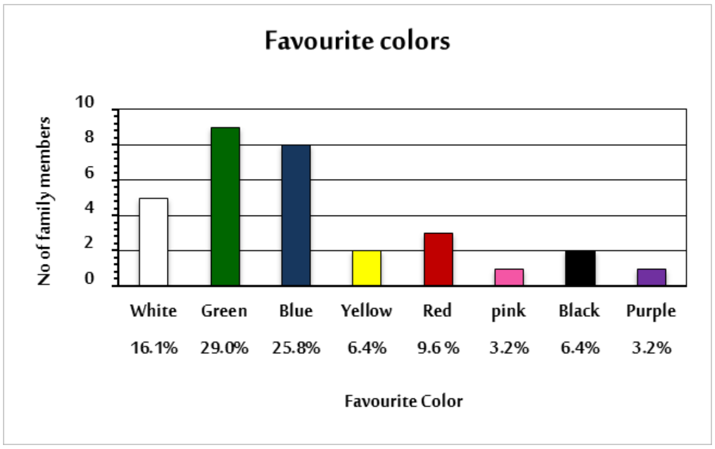

Figure 11: Colour preference

Note: The majority (58%) selected cool colours (Green, blue and purple) as their favorite colours while 22.5% liked neutral colours (Black and white) and only 19.2% selected warm colours (Red, yellow and pink) as their favourite colours.

Perception of new colour scheme vs. Previous colour scheme

Question answered: Did you feel any difference between the new colour scheme and the previous colour scheme? (Yes / No / Neither) Other suggestions if any……

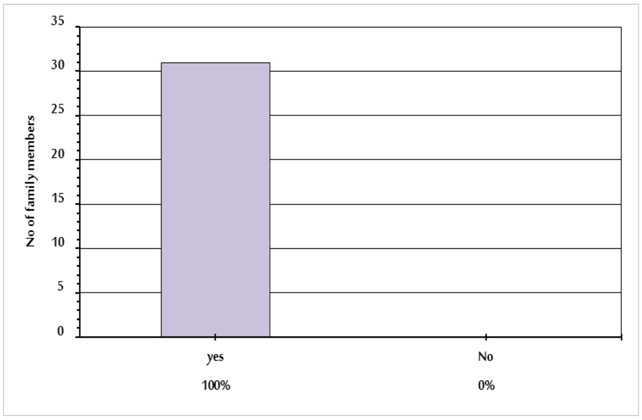

Figure 12: Perception of new colour scheme vs. Previous colour scheme

Note: 100% perceived a difference between the previous and the new colour schemes.

Type of the perceived difference between new and the previous colour scheme

Question answered: What type of a difference did you feel from the new colour scheme? (Positive, neither positive nor negative, negative)

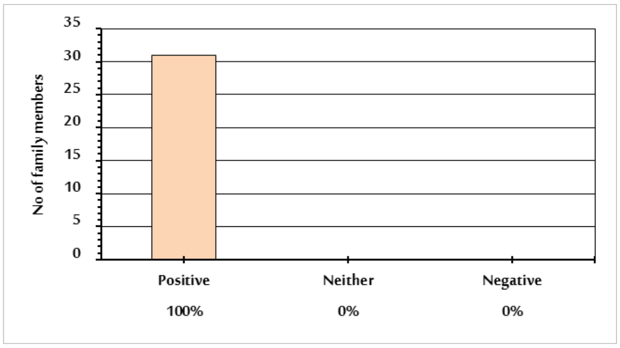

Figure 13: Perception of new colour scheme vs. Previous colour scheme

Note: 100% were positive with new colour scheme.

Spontaneous thermal perception in general

Question answered: Did you feel any variation in thermal perception associated with the new colour scheme? (Strongly agree /agree/ neither/

Disagree/Strongly disagree) Other suggestions if any…….

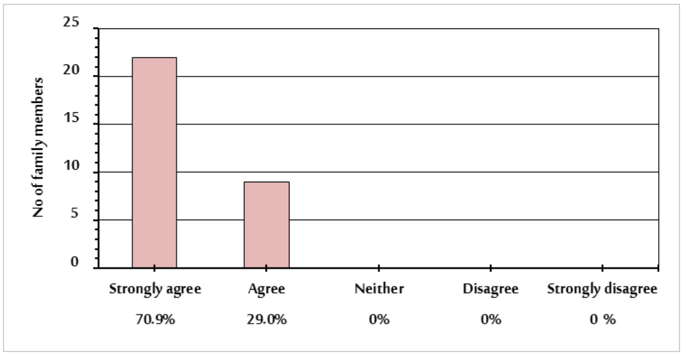

Figure 14: Spontaneous thermal perception in general

Note: Being on par with hypothesis, majority (99.9%) regardless of the variations of age and gender felt a thermal perception variation in new colour scheme against the previous. Most of them agreed (99.9%) that they felt a difference in room temperature especially during the night time.

Thermal perception associated with red (Cranberry Zing) room

Question answered: Describe your thermal perception in the red colored room?
(Warm / slightly warm / neutral / slightly cool / Cool)

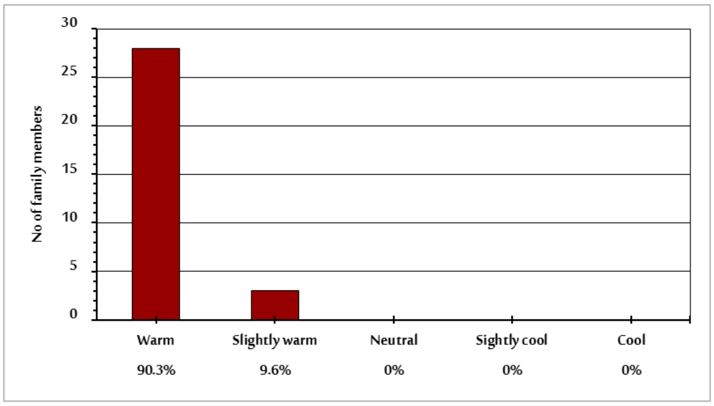

Figure 15: Spontaneous thermal perception in general

Note: A majority (99.9%) of participants perceived red room to be warmer (90.3% strongly agreed and 9.6% agreed).None of them perceived it to be cooler.

Few noteworthy comments made by the participants of the seven houses on the impact of colour red in general and associated thermal perception are quoted below.

A young boy (18 yrs.) of house two – "I feel that my bed room is warmer than what I felt before due to the introduction of red colour"
A boy (13 years) of house five – "I slept well than previously in my red coloured bed room, because of its warmth"
Old person (64 years) in house four – "I got muted when I saw the red room at once"
A lady (42 years) of house six (a Hindu family) – "We like red coloured room as red is very much closer to our religion"

On the other hand as a significant finding, the participants highly preferred the red room suggesting their sensitivity to colour red.

Thermal perception associated with blue (duck egg blue) room

Question answered: Describe your thermal perception in the red colored room? (Warm / slightly warm / neutral / slightly cool / Cool)

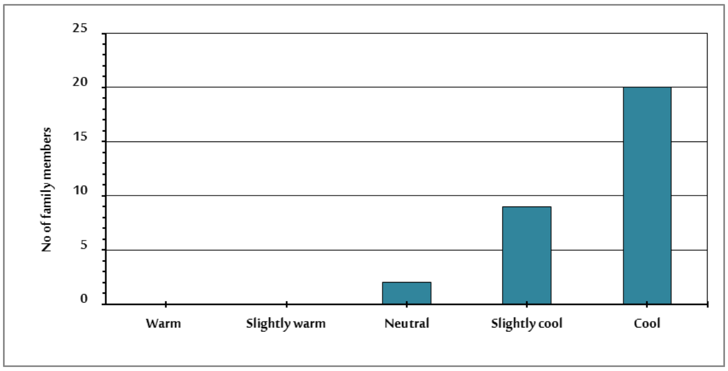

Figure 16: Spontaneous thermal perception in general

Note: A majority (93.5%) perceived blue to be cool (64.5% strongly agreed, 29% agreed) and 6.4% remained neutral. None of them perceived the room to be warm.
Two interesting points which the author noted among the comments made on the impact of colour blue in general and on thermal perception are attached below.
A young girl (20 yrs.) in house two – "I felt very uncomfortable last night in blue room, because it 'was very cold than previous days."
A lady (59 yrs.) in house two – "Blue is a beautiful colour, but I like red coloured interior"
Accordingly preference to the blue room was less compared to the red room.

Preference comparison - Cranberry Zing room vs. Duck egg blue room

What is the room that you prefer most in terms of the colour scheme? (Cranberry Zing room/. Duck egg blue room)

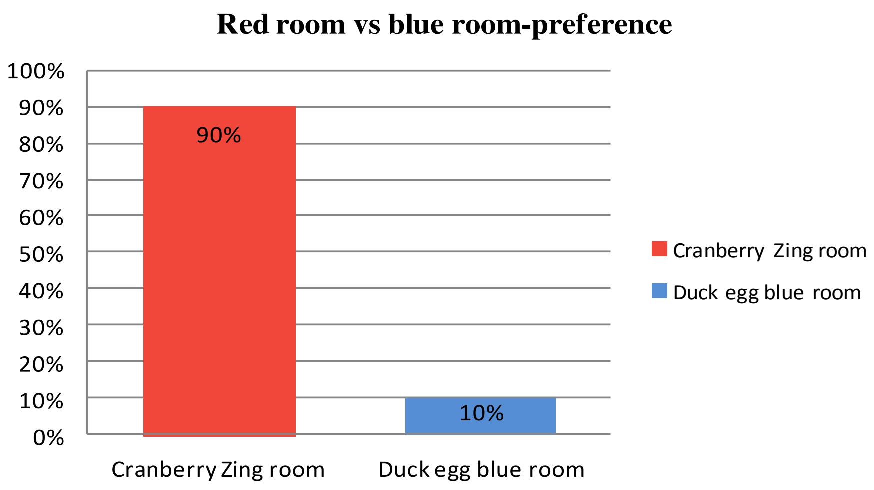

Figure 17: Red room vs. blue room-preference

Note: The majority of participants preferred the red room most (90%) whereas only 10% preferred the blue room.

Analysis and Conclusions

When it comes to the colour preference of the participants, it was revealed that cool colours were dominating as their favorite colours (58.0% - green, blue and purple) while 22.5% selected neutral colours (black and white) and only 19.2% selected warm colours (Red, Yellow and Pink) as their favorite colours. Warm colours were not dominating as their favorites as anticipated by the investigator. This preference to some extent can be as a result of long term psychophysiological adaptation, acclimatization and familiarization to a cold climatic condition characterized by a cool pacifying ambience.

All the participants of the seven houses involved (100%) were positively responding to the new colours in their bed rooms. This however could be explained as a common psychological reaction to a new change applied within a long existing situation, especially in terms of a colour scheme. However considering their personal comments as well as the spontaneous reactions triggered by the two new colour schemes applied, it was revealed that even though a majority possess a cool favorite colour, they were much sensitive and responsive to red room against blue room (Red - 90%, Blue – 10%). They remarkably preferred red room and showed a lesser interest on the blue room. As the underlying reason for this finding, it can be suggested that people who are psychophysiologically adapted to cool climatic conditions in long term basis would be very much sensitive and prefer warm conditions than the usual cool conditions so does their response to a warm colour vs. a cool colour.

Substantiating the hypothesis, it was revealed that the participants significantly perceived a change between the new and previous colour schemes in thermal terms (70.9% - strongly agreed and 29.0% agreed). Regardless of the participants age or gender, the majority consistently (99.9%) perceived red room to be warmer (90.3% strongly perceived and 9.6% perceived).On the other hand 93.5% perceived Blue room to be cooler (64.5% strongly perceived and 29% perceived while 6.4% remained neutral). This finding substantiates the ability of colour red (warm colours) to induce a warm perceived thermal ambiance against the actual cold thermal condition. This is a positive association which can be used to create habitable interiors in cold climatic conditions contributing to a thermally comfortable better living environment. Supported by the psychologically induced warm thermal perception, introducing warm colours to a cool climatic situation will make people more active and energetic to counteract the cool pacifying ambiance. This in turn will allow them to reduce the heating cost to some extent in the interiors where a heating system is used. On the other hand the study reveals that integrating cool colours in the interiors of a cold climatic condition works negatively as the participants perceive the interior as even cooler than the actual condition making the situation even worse. This will unnecessarily increase the heating cost.

In conclusion, this study identifies colour as a most potential tool to manipulate the perceived thermal ambience in interiors of cold climatic regions. Significantly, the study recommends integrating warm colours when designing interiors in cold climatic regions to create a thermally comfortable environment while discouraging the use of cool colours. Further it is recommended to develop the research design with reference to interiors where a heating system is involved to test the possibility of energy conservation as a future direction. It is also suggested to test the reverse principle of integrating cool colours to create thermally comfortable interiors in hot humid climatic conditions eventually contributing to saving of cooling costs.

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