

LOCATION PLANNING TOOL FOR BIOMASS BOILERS

S.Y.R. Jeewakaratna

(148481A)

Degree of Master of Engineering

Department of Mechanical Engineering

University of Moratuwa

Sri Lanka

January 2020

LOCATION PLANNING TOOL FOR BIOMASS BOILERS

S.Y.R. Jeewakarathna

(148481A)

Thesis / Dissertation submitted in partial fulfilment of the requirements for the degree
Master of Engineering

Department of Mechanical Engineering

University of Moratuwa
Sri Lanka

January 2020

DECLARATION

This report contains no material which has been accepted for the award of any other degree or diploma in any University or equivalent institution in Sri Lanka or abroad, and that to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference is made in the text of this report.

I carried out the work described in this report under the supervision of Dr. Himan Punchihewa.

Signature : Date :

Name of Student : S.Y.R. Jeewakaratna

Registration No : 148481 A

Signature : Date :

Name of Supervisor : Dr. H.K.G. Punchihewa.

Abstract

Steam boilers constitute an important part of a production facility. Though traditionally, fossil fuel has been used predominantly in steam boilers, the environmental impacts of using fossil fuel and the higher economics have fuelled exploration on alternative fuels such as biomass and in 2016 demand for biomass energy in Sri Lanka has been 194.3 PJ out of which 75.8 PJ has been industry demand which is an increase of 300 TJ compared to previous year.

In light of above, this study has been carried out with the aim of mitigating the environmental impacts of using biomass as a fuel for boilers in Sri Lanka and to improve related economics by developing a location planning tool for biomass boilers & with the objectives of assessing factors that would govern the environmental and financial costs associated with the operation of a steam boiler with respect to heavy oil and biomass variants leading to proposing of a framework to rank the fuel variants based on environmental performance and finances.

Methodology followed in this study was carrying out a life cycle assessment (LCA) to assess the environmental loads of each biomass variant in context via data collected in surveys and analysing reports of 60 steam boilers followed by comprehensive financial analysis and sensitivity analysis enabling comparison of relative contribution of each step in the process.

It was identified due to extremely adverse impact of using fossil fuel, using biomass where sustainable has become the best alternative regardless the location of the boiler and subsequent distance from biomass source to the application, in Sri Lankan Context, consequently the threshold points for switching to biomass lie in the economic factors as cost of transportation dominates whether the process is feasible. Sawdust was identified as the most environmentally friendly fuel followed by wood chips, wood logs and husk respectively. Distances from wood log, husk, wood chip, and sawdust biomass sources to the point of application to equal the financial cost of heavy oil-based boiler operation were identified as 530 km, 554 km, 595.5 km and 604 km respectively. It was identified, ranking order of financial performance of fuels, toggle along with distance from respective biomass source to point of application, such that a fuel more feasible compared to another at similar relatively lower distance from fuel source to point of application would not necessarily be so at higher similar distances. Though husk usage is costlier than sawdust at relatively smaller distances, at similar distances over 140 km from respective fuel source to point of application, sawdust becomes the more viable fuel. Similarly, chips usage though expensive at relatively lower similar distances equivalent to other biomass variants, becomes more viable compared to husk and wood logs at similar distances over 460 km and 355 km respectively.

Precise data on biomass sources in Sri Lanka are lacking and taking measures to develop a biomass resources map would contribute to location planning process of biomass boilers favourably and streamline supply chain process.

Acknowledgements

I would like to express my deepest appreciation to Dr. Himan Punchihewa, my supervisor for this study for his patient guidance, advice and sharing time to discuss the matters.

My thanks are extended to Dr. Manoj Ranaweera, the course coordinator of this programme and Professor Ruwan Gopura, the Head of Department of Mechanical Engineering for their efforts to coordinate and ascertain the programme ends in a success.

I'm forever indebted to my parents, family and friends for their love, support and encouragement.

Contents

Declaration -----	i
Abstract -----	ii
Acknowledgements -----	iii
Contents-----	iv
List of Figures-----	vi
List of Tables-----	vii
List of Abbreviations-----	ix
1 Introduction. -----	1
1.1. Introduction to the study-----	1
1.2. Aims & objectives of the study -----	3
1.3. Methodology -----	3
1.4. Dissertation structure-----	3
2 Literature Review -----	4
2.1. Environmental effects of steam generation via fossil fuel combustion-----	4
2.2. Environmental effects of steam generation via biomass combustion-----	5
2.3. Existing LCA studies and supply chain model on biomass fired steam boilers -----	6
2.4. Biomass fired steam generation in Sri Lanka -----	8
2.5. Life cycle assessment to determine environmental impact-----	8
2.5.1. Life cycle assessment software-----	11
3 Methodology-----	13
3.1. Data collection -----	13
3.1.1. Emission inventory of electricity generation -----	13
3.1.2. Boiler emissions in steam generation-----	16
3.1.3. Drying of biomass -----	19
3.1.4. Emissions in transportation -----	20
3.1.5. Cost of operation with respect to biomass fuel alternatives -----	21
3.1.6. Availability of biomass variants -----	22
3.1.7. Electricity consumption -----	26
3.2. Life cycle assessment methodology-----	27
3.2.1. Goal and scope definition -----	28

3.2.2. Life cycle inventory analysis -----	30
3.2.3. Life cycle impact assessment-----	31
3.3. Financial analysis of boiler operation with respect to alternative fuels-----	34
3.4. Sensitivity analysis -----	34
4 Results -----	35
4.1. Framework & tool for location planning of biomass boilers-----	35
4.1.1. Data collection-----	35
4.1.2. Life cycle assessment-----	36
4.1.3. Financial assessment-----	36
4.1.4. Sensitivity analysis-----	36
4.1.5. Ranking-----	36
4.2. Validation of case study -----	36
4.2.1. Life cycle assessment of boiler operation with respect to alternative fuels-----	36
4.2.2. Financial analysis of boiler operation with respect to alternative fuels -----	43
4.2.3. Sensitivity analysis based on distance-----	46
4.2.4. Ranking alternative fuels-----	49
5 Discussion-----	52
6 Conclusions -----	56
References-----	57

List of Figures

Figure 2.1: System boundary of a biomass boiler -----	6
Figure 2.2: Characterisation of impacts -----	7
Figure 3.1: Extent of rubber plantation by district -----	25
Figure 3.2: Boundary of biomass fired boilers -----	29
Figure 3.3: Boundary of heavy oil-fired boilers -----	30
Figure 3.4: Classification of environmental interventions into selected impact categories ---	32
Figure 4.1: Framework & tool for location planning -----	35
Figure 4.2: Relative results -----	39
Figure 4.3: Normalised results -----	42
Figure 4.4: Relative results at transportation distances of 1000 km -----	43
Figure 4.5: Operational cost variance of biomass variants along with distance	51

List of Tables

Table 2.1: Groups of impact categories	10
Table 3.1: Gross power generation by sector.....	14
Table 3.2: Power generation contribution percentages of various fuel categories	15
Table 3.3: Total petroleum fuels in power generation.....	15
Table 3.4: GHG and other emissions by oil due to electricity generation.....	15
Table 3.5: GHG and other air emissions due to coal	16
Table 3.6: Emissions of rice husk burning.....	16
Table 3.7: Chemical composition of rice husk ash.....	17
Table 3.8: Ultimate analysis of sawdust	17
Table 3.9: Emissions of sawdust burning	18
Table 3.10: Emissions of wood log burning.....	18
Table 3.11: Emissions of heavy oil-fired boiler.....	19
Table 3.12: Emissions of wood chip burning	19
Table 3.13: Emissions of road transport sub-sector in 2000.....	20
Table 3.14: Cost of different categories of biomass	21
Table 3.15: Biomass requirement to generate one tonne of steam from and at 100 °C.....	21
Table 3.16: Transportation loads and mileage of various transportation vehicles	22
Table 3.17: Paddy production in Sri Lanka by district	23
Table 3.18: Extent of rubber plantation by district.....	24
Table 3.19: Electricity consumption per generation of one tonne of steam from various biomass variants.....	27
Table 3.20: Selected impact categories and respective characterisation factors	33
Table 3.21: Normalisation factors.....	34
Table 4.1: Inventories of one tonne of steam generation.....	37
Table 4.2: Characterisation results of impact categories	38
Table 4.3: Relative contribution of each process of husk fired steam generation	39
Table 4.4: Relative contribution of each process of wood log fired steam generation.....	40
Table 4.5: Relative contribution of each process of wood chip fired steam generation.....	40
Table 4.6: Relative contribution of each process of sawdust fired steam generation.....	40
Table 4.7: Relative contribution of each process of heavy oil-fired steam generation.....	41
Table 4.8: Normalised results	41
Table 4.9: Characterised results at transportation distances of 1000 km.....	42

Table 4.10: Single scores at transportation distances of 1000 km.....	43
Table 4.11: Operational cost of one tonne of steam without accounting transportation	44
Table 4.12: Operational cost of one tonne of steam accounting transportation - Base case...	44
Table 4.13: Single score LCA results of sensitivity analysis.....	46
Table 4.14: Financial cost variance of steam generation via sawdust and husk along with distance from fuel source	47
Table 4.15: Financial cost variance of steam generation via wood chips and husk along with distance from fuel source	48
Table 4.16: Ranking of fuel variants based on environmental & financial factors	50

List of Abbreviations

CEB	Ceylon Electricity Board
CH ₄	Methane
CO	Carbon monoxide
CO ₂	Carbon dioxide
GHG	Greenhouse gas
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
N ₂ O	Nitrous oxide
NMVOOC	Non-methane volatile organic compounds
UK	United Kingdom
USA	United States of America
kWh	kilowatt hour
GWh	Gigawatt hour
kt	kilo tonne
MT	Metric tonne
kCal	kilo Calorie
ha	Hectare
LKR	Sri Lanka rupee
Ltr	Litre
MJ	Megajoule
TJ	Terajoule
PJ	Petajoule
PM	Particulate matter