Dissertationes Forestales 210

Supply and demand of biomass based energy: rural people's perspectives in Bangladesh

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Academic dissertation

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ABSTRACT

Biomass is the most common and significant indigenous source of energy in rural areas of Bangladesh. The widespread use of biomass for energy is a source of concern as it may lead to overexploitation of forest resources and the conversion of woodlands to other non-forestry purposes, which potentially have negative impacts not only for climate change but also for local food and fuel production. Moreover, a lack of comprehensive data on resource availability, biomass consumption patterns, and the absence of information in regard to public attitudes and knowledge of biomass fuels in general have been recognized as major obstacles to the development of modern and efficient biomass based energy use in Bangladesh. This study examines four aspects of bioenergy in Bangladesh: the bioenergy potential, the energy consumption patterns of rural households, the preferences and attitudes of rural households towards biomass fuels, and finally their knowledge and perceptions of sustainable energy development.

The results revealed that the recoverable bioenergy potential from selected crop residues and wood fuels amounted to about 762 million GJ in 2009. However, the potential is predicted to reach 946 million GJ by 2020 under the “status quo” benchmark levels and could reach a maximum of 1236 million GJ under higher GDP growth rates (Article I). Biomass fuels were identified as the predominant source of primary energy supply. Per capita primary energy consumption was estimated at 6.45 GJ/year with the proportion from biomass fuels estimated at about 6.03 GJ (equivalent to 93% of the total energy consumption) (Article II). The study showed that biomass fuel consumption is influenced by family size, per capita income, and per capita land. Firewood was the most preferred biomass fuel followed by cow dung, bamboo and jute stalk (Article III). However, due to the continuous decline in the tree resources, the availability of firewood is now in short supply. On-farm and off-farm tree planting have become more important among rural households in response to the acute lack of firewood supply.

Recognizing the importance of public knowledge on the development of renewable energy, the study found that rural households possessed a high level of knowledge of traditional biomass fuels; however, they had a relatively low level of knowledge on newer biofuels and other renewables (Article IV). This implies that there is a need for the dissemination of information in regard to bioenergy and other renewable energy technologies among the rural populace. Depletion of tree resources, inadequate afforestation programmes, and a lack of initiatives towards the utilization of set-aside lands for wood energy plantations has been identified as the major impediments to biomass-based energy development in Bangladesh. Analysis showed that an enhancement of the afforestation programme, building public awareness of energy technologies, and the formulation of ‘biomass-based rural energy strategies’ are relevant for the development of sustainable biomass based energy in Bangladesh. The results provide detailed information on bioenergy and other renewable energy dynamics, which are useful in the development of microplans for the forestry and energy sectors at local, regional and national levels.

Keywords: Bioenergy potential, rural household, biomass consumption, preference, attitude, knowledge, perception

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Joensuu, December 2015
Md. Kamrul Hassan

LIST OF ORIGINAL ARTICLES

This doctoral thesis is based on the following four scientific articles, which are referred to in the text by the Roman numerals I-IV. The Articles I to IV are reproduced with the kind permission of the publishers.

I Hassan K.M., Pelkonen P., Pappinen A. 2011. Assessment of bioenergy potential from major crop residues and wood fuels in Bangladesh. Journal of Basic and Applied Scientific Research 1(9): 1039-1051.

II Hassan K.M., Pelkonen P., Halder P., Pappinen A. 2012. An analysis of cross-sectional variation in energy consumption pattern at the household level in disregarded rural Bangladesh. Journal of Basic and Applied Scientific Research 2(4): 3949-3963.

III Hassan K.M., Pelkonen P., Halder P., Pappinen A. 2013. Rural households' preferences and attitudes toward biomass fuels – results from a comprehensive field survey in Bangladesh. Energy, Sustainability and Society 3(24): 1-14.
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IV Hassan K.M., Pelkonen P., Pappinen A. 2014. Rural households' knowledge and perceptions of renewables with special attention on bioenergy resources development - Results from a field study in Bangladesh. Applied Energy 136: 454-464.
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Md. Kamrul Hassan was primarily responsible for the design of the study plan, the preparation of survey tools, conduction of field surveys, the analyses of the data, and the writing of the manuscripts of all articles (Article I-IV). The co-authors have participated in the work by formulating the research task, and commenting on all manuscripts.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AEZ	Agro Ecological Zone
BBS	Bangladesh Bureau of Statistics
BDT	Bangladesh Taka
BFD	Bangladesh Forest Department
BPDB	Bangladesh Power Development Board
BSRRSO	Bangladesh Space Research and Remote Sensing Organization
DCENR	Department of Communications, Energy and Natural Resources
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FMP	Forestry Master Plan
GDP	Gross Domestic Product
GJ	Giga Joule
GoB	Government of Bangladesh
IEA	International Energy Agency
IMF	International Monetary Fund
kWh	Kilo Watt-hours
LGED	Local Government Engineering Department
LHV	Lower Heating Value
m^3	cubic meter
MJ	Mega Joule
MDG	Millennium Development Goal
MCFD	Million Cubic Feet per Day
MoEF	Ministry of Environment and Forests
MW	Mega Watt
NCS	National Conservation Strategy
NEA	Nuclear Energy Agency
NEAP	National Environment Action Plan
NEMAP	National Environment Management Action Plan
NEP	National Energy Policy
OECD	Organization for Economic Co-operation and Development
PCA	Principal Component Analysis
PJ	Peta Joule
PRSP	Poverty Reduction Strategy Paper
RESs	Renewable Energy Sources
SD	Sustainable Development
SRF	Short Rotation Forestry
t	metric ton

TCF	Trillion Cubic Feet
TPES	Total Primary Energy Supply
TWh	Tera Watt-hours
UN	United Nations
UNEP	United Nations Environment Programme
WCED	World Commission on Environment and Development
α	alpha
$	U.S. Dollar

1 INTRODUCTION

1.1 Background

The prolific use of fossil fuels has resulted in high carbon dioxide (CO_2) and other greenhouse gas emissions that are predicted to cause enormous changes to the global climate (IPCC 2013). The adverse impacts of fossil fuels and the importance of alternative renewable energy sources have become important political issues globally. Therefore, the development of renewable energy sources and sustainable energy concepts are tremendously important for all countries (UNEP 2008). Biomass appears to be an important contributor to future global sustainable energy (Berndes et al. 2003). More than half of the global population lives in the rural areas of developing countries where most people depend mainly on biomass for their primary energy supply, and do not have access to "modern" forms of energy (Demirbas and Demirbas 2007). Biomass and its' modern technologies offer the prospect of clean energy services, which are often cost-wise competitive with fossil fuels. Rural socio-economic aspects of bioenergy, such as biomass resource availability, current biomass consumption patterns, emerging bioenergy technologies, public perceptions and acceptance of bioenergy are important elements for future sustainable energy development from local to global levels.

Bioenergy is expected to play a substantial role in future energy systems as a substitute to fossil fuels for three main reasons. First, it is a renewable energy source (RES) that could be sustainably developed in the future; second, it is CO_2 neutral (and also has a very low sulfur content); and third, it provides a secure energy supply that could have significant economic potential in comparison to fossil fuels (Tonn 2002). Despite the obvious potential, the contribution of bioenergy to global energy consumption is very low. In 2012, it amounted to 10% of the total primary energy supply (TPES), which constituted about 80% of all renewable energy used globally (IEA 2014).

Bioenergy is mainly derived from three types of feedstock, namely forest, agricultural and waste biomass. They are commonly used as a fuel for both commercial and non-commercial purposes. Biomass constitutes the most significant indigenous source of energy in many countries in Asia and the Pacific region, such as Bangladesh, Bhutan, Cambodia, India, Laos, Myanmar, Pakistan, Sri Lanka, and Vietnam (Koopmans 2005). In rural Bangladesh, biomass is the predominant fuel source for the supply of primary energy. Rural households mainly use local wood-based biomass, agricultural crop residues and animal dung as fuel for meeting their daily energy demand. The average rural household meets about 41% of their biomass fuel demand from wood fuels, 39% from crop residues and the remaining 20% from animal dung and other non-wood biomass such as grass, litter etc. (Asaduzzaman et al. 2010). However, little is known about bioenergy resource availability, biomass consumption patterns, and the end-users' attitudes towards production and development of this resource. As a result, much uncertainty exists in regard to environmental concerns and the sustainable use of this resource.

1.2 Overview of the energy situation in Bangladesh

Bangladesh is located in the northeastern part of South Asia. The country has a high population density, low income levels and consequently low energy consumption. The country has very limited land resources. The total land area is only 14.76 million hectares of which arable land accounts for 56%, forest land 10%, inland water close to 14%, and human habitation and development areas about 20% (BFD, BSRSSO, and FAO 2007). According to the 2011 census, the population of the country is 142.32 million with an average annual growth rate of 1.34% (BBS 2012). Per capita annual energy consumption in 2012 was 8.98 GJ (gigajoules), which was one of the lowest in the South Asian region (IEA 2014). The total primary energy consumption in Bangladesh in 2012 was 1388.76 PJ (petajoules) of which about 72% of conventional energy was supplied from indigenous sources and the remaining 28% from imported oil (IEA 2014). Biomass, natural gas, and coal are the main indigenous fuel sources for the supply of primary energy in the country.

Bangladesh currently faces a daunting energy shortage. For instance, average power generation is about 6000 MW (megawatts), whereas the average demand is about 7500 MW (Huda et al. 2014). Thus, power shortage causes excessive load shedding throughout the whole year and the situation becomes even worse during the summer months when the capacity gap between electricity demand and supply grows by up to 1500 MW. Power generation is almost totally dependent on natural gas and petroleum oil. In 2011, the contribution of natural gas and petroleum oil amounted to 78% and 17% respectively of the total installed electricity generation capacity (6639 MW) (BPDB 2012). Other sources of electricity generation are coal and hydropower, and they contribute 2.7% and 2.3% of total electricity generation, respectively. Per capita electricity generation in 2011 was 232 kWh, which was one of the lowest in the South Asian region (BPDB 2012). In Bangladesh, approximately 55% of the population has access to grid electricity, whereas in rural areas accessibility is about 40%. Demand for electricity has steadily increased at an annual rate of 10% during the last 10 years (BPDB 2012). Although, the Government of Bangladesh (GoB) has declared that it will provide electricity to the whole of the country by 2021, the current gap between electricity demand and supply has widened considerably, and would indicate an enormous power shortage in the country in the foreseeable future if adequate measures are not taken now. The electricity supply crisis is even more severe in rural areas where 77% of the population lives. Moreover, electricity services in rural areas are very poor, subject to erratic supply, unreliable and frequent voltage fluctuations. Rural households mainly use electricity for lighting, household appliances, and for agricultural activities (mainly irrigation purposes). In the rural areas of Bangladesh, the main portion of energy is consumed for household cooking. A study from rural areas of Northern Bangladesh showed that 84% of energy is consumed for cooking and rice parboiling, 13% for irrigation and only 3% for lighting (Sarkar and Islam 1998). Rural households use kerosene and electricity for lighting. Some 70% of lighting energy is derived from kerosene and the remaining 30% from electricity (Asaduzzaman et al. 2010). Households connected to grid electricity use kerosene lamps for lighting as a backup in case of power failure. Nevertheless, in rural Bangladesh the supplying of energy for cooking and rice parboiling is crucial. Over 90% of rural households depend totally on biomass fuels for their daily energy demand, especially for cooking and rice parboiling (Islam et al. 2008). Furthermore, 3-4% of rural households use natural gas for cooking, and less than 3% rely on kerosene and coal for the same purpose.

In Bangladesh, the contribution of biomass fuels in TPES is around 60% (Hossain 2005; Islam et al. 2008; Hasan et al. 2013). Agricultural residues, wood fuels and animal dung are the main sources of biomass fuels (Islam et al. 2008). Biomass fuels are collected from local environment. Consumption of biomass fuels varies with localities. For instance, per capita annual consumption of biomass fuels in urban areas is 319 kg whereas in rural areas,

Table 1. Wood and other biomass stocks on different land-use classes

Land-use class	Area (million ha)	% of total land	Gross wood growing stock (million m^3)	Average wood growing stock (m^3/ha)	Above ground biomass (million tonnes)	Average above ground biomass stock (tonnes/ha)
Forest land	1.44	9.8	70	48.3	278	193
Cultivated land	8.33	56.4	36	4.3	142	17
Village area	2.86	19.4	103	36.1	413	144
Urban area	0.10	0.7	2,4	23.3	10	93
Inland water	2.02	13.7	1	0.5	4	2
Total/Average	14.7	100	212	15	847	57

Source: BFD, BSRRSO, FAO (2007)

the consumption is 432 kg (Islam et al. 2008; Asaduzzaman et al. 2010). Bangladesh has limited forest resources and forest land covers only 1.44 million ha or 9.8% of the total land area (Table 1). The most recent inventory showed that the gross wood growing stock was about 212 million m^3 and the gross above ground biomass stock was about 847 million tonnes (BFD, BSRRSO and FAO 2007). Trees and other biomass in village areas are the main sources of biomass fuels in the country. However, the heavy dependency on biomass fuels from limited resources, lower growing stock per unit of land and the high population density has put immense strain on existing biomass resources.

Natural gas and coal are the main indigenous non-renewable energy sources in the country. Natural gas is mainly used for power generation, fertilizer production, other industrial applications, and the household sector, which account for 40%, 22%, 17% and 11% of the total production, respectively (BBS 2010). By January 2013, 25 natural gas fields had been discovered with an estimated proven recoverable reserve of 16.12 TCF (trillion cubic feet). Current reserves are forecast to last for 30 years based on the present rate of consumption (Petrobangla 2014). However, the average daily supply of gas from all domestic gas fields is about 2000 MCFD (million cubic feet per day) against the regular demand of 2500 MCFD, leaving a daily shortfall of about 500 MCFD (Energypedia 2014).

Coal is expected to be the main feedstock for electricity generation in the near future (Murshid and Wiig 2001). There are five coal mines in the country with a total in-situ proven and probable reserve of about 3300 million tonnes. To date, only one coal mine has been developed, viz. Barapukuria where commercial production started in 2005 with an annual target of 1 million tonnes. The average amount of recoverable coal is 0.6-0.8 million tonnes per year. Extraction of these coal deposits is planned as an alternative to gas as a fuel source in power plants. One coal-based power plant has been already constructed at Barapukuria and has been in operation since 2006 with a capacity of 250 MW. The government has also planned to install five other coal-based power plants with a total capacity of 3500 MW during the 2012-2016 period. In addition to natural gas and coal, there is about 170 million tonnes of peat located in the southern regions of the country. However, exploratory studies have shown that power generation from peat is not economically viable; therefore, the use of peat as a commercial fuel was discouraged (GoB 2004).

Bangladesh has one hydropower station; the 'Karnafuli Hydroelectric Power Station', which was commissioned between 1962 and 1988. The water storage capacity of this plant is 6477 million m^3 with a catchment area of 11000 km^2. Although the total installation capacity of this plant is 230 MW, only a part of it is actually harnessed. Aside from hydropower, the country has a potentially immense solar power resource. About 94% of the country receives average daily solar radiation of between 4-6.5 kWh/m^2; average sunny hours per day are 6.5 and the annual mean solar radiation is 0.2 kW/ m^2, which would indicate that, in theory, Bangladesh receives about 69751 TWh (Tera Watt-hours) of solar energy each year (Mondal and Denich 2010). However, a number of barriers (i.e. policy, institutional, technical, financial) restrict the exploitation of this resource. In regard to wind energy conversion systems, the estimated installation potential in Bangladesh is about 4614 MW; however, only a small part (average 50kW) has actually been harnessed (Mondal and Denich 2010). The two main wind power projects are at Kutubdia Island in Cox's Bazar district with an installation capacity of 1000 kW and in the Muhuri Dam area in the Feni district with an installation capacity of 900 kW. Insufficient funding, lack of initiatives for long-term operations and maintenance are the main impediments to wind energy development in Bangladesh (Bahauddin and Salauddin 2012).

1.3 Energy policies in Bangladesh and their implications

With recognizing the importance of energy in socio-economic development in the country, GoB declared a 'National Energy Policy 1995', which aimed to improve conditions for developing energy sectors during the period 1995-2020. It was recognized as the first National Energy Policy (NEP) and came into force in 1996. The NEP set a number of objectives and the most important of them were (1) to reduce energy supply disparity between different regions of the country and between different socio-economic groups; (2) to maximize development of all indigenous energy sources; and (3) to enhance environmental sustainable energy usage while causing minimum damage to the environment. The NEP mainly focused on the development and planning of the power sector (i.e. fossil fuel-driven power plants). The government developed a five-year plan (2012 to 2016) to implement projects that would increase the power generation capacity from 8100 MW to 12000 MW (BPDB 2012). Again, this mainly focused on the installation of furnace oil-based and imported coal-based power plants. As a result, the share of CO_2 emissions from fossil fuel-based power plants in the national CO_2 inventory has increased while at the same time dependency on imported fossil fuels for power generation is likely to continue to increase. In fact, the power sector alone contributes more than 40% of the total national CO_2 emissions (ADB 1998). The increasing use of fossil fuels to meet the growing demand for electricity has been recognized as a general trend in developing countries like Bangladesh, (Mondal and Denich 2010). However, such practices not only increase foreign expenditure, but also lead to climate vulnerability and have a negative impact on the environment. In regard to the energy context in Bangladesh, it is imperative to develop and to promote renewable energy resources. It has been shown that the power sector alone is unable to cope with the growing demand for energy countrywide (Islam et al. 2008). Therefore, policy directives on renewable and biomass-based rural energy programmes are important and need to be emphasized in energy policy frameworks (Islam 2001; Miah et al. 2010; Islam et al. 2011).

Nevertheless, the government adopted the 'Renewable Energy Policy 2008' in accordance with global issues on declining fossil fuel availability, a reduction in global greenhouse gas emissions, and the promotion of energy security. The policy aims to promote clean energy from different renewable sources, especially solar, wind, hydro and biomass resources thorough the establishment of institutional arrangements (GoB 2008). The policy set a target to achieve 5% of power generation from renewable resources by 2015 and 10% by 2020. The policy has also emphasized biomass-based electricity generation technologies and has set up the Sustainable Energy Development Agency (SEDA) for institutional assistance. However, both NEP and the 'Renewable Energy Policy 2008' have lacked strong guidelines in the development of biomass-based energy in rural areas where consumption of biomass fuel is substantial. Formulation of biomass-based rural energy strategies is therefore important to achieve a sustainable biomass fuel supply, especially for rural households who mostly depend on it for their cooking energy requirements.

1.4 Challenges of bioenergy development in Bangladesh

Wood fuels, agricultural residues and animal dung are intensively used for domestic, commercial and industrial applications in Bangladesh. Wood fuels are mainly supplied from homestead trees, plantations on marginal lands and government owned forests. Wood fuel production in the country has remained stable since 1990 at about 27 million m^3/year (FAOStat 2013). At the same time, the population has grown 1.5% annually and per capita primary energy consumption has increased by 51% from the 1990 level (per capita energy consumption was 5.95 GJ in 1990). The combination of high population growth and increased energy demands has put tremendous pressure on existing biomass fuel resources, especially wood biomass. Moreover, low per capita land holding is one of the major challenges for production of wood-based biomass fuels (per capita arable land is only 0.05; one of the lowest in the world). This means that little land is available for the population to sustain their livelihood in regard to food, fuels and building materials. Conversion of woodland to non-forestry purposes is one of the major concerns for the sustainable supply of wood fuel in the country. In addition, a lack of long-term governmental afforestation, reforestation, and forest enrichment programmes, a lack of coordination among governmental departments on land and forest management, weak institutional governance, lack of commitments on the implementation of forestry related policies and plans were identified as the main impediments to wood-based biomass development in Bangladesh (FAO 2011).

Although crop residues are frequently used by rural households as fuel, the consumption of such fuels is, however, inefficiently used (LGED and FAO 2006). Residues from rice and other crops are recognized as promising for bioenergy production. However, due to technical, financial, institutional, policy and information barriers, crop residues-based biomass technologies have not yet reached the commercialization stage (LGED and FAO 2006). In addition to wood fuel and crop residues, animal dung has also traditionally been used as a fuel by most rural households and by many small-scale enterprises. Poor women and children are generally involved in the collection of animal dung, and in the processing and preparation of fuel cakes. They often collect animal dung from open areas, such as open agriculture fields and village roads. However, the availability of animal dung is increasingly limited due to the decrease in the number of cattle, decreased/increased farm sizes, restriction of open grazing facilities, conversion of wasteland to agricultural lands, and increased agricultural mechanization (FAO 2000).

A paucity of sustainable biomass-based energy strategies and policies, as well as their poor implementation due to minimal financial and human resources at both the regional and the national level could be limiting factors in the development of biomass-based energy in Bangladesh (Ahiduzzaman 2007; Miah et al. 2010). Addressing these barriers could eventually contribute to a reduction in climate change related impacts and socio-economic vulnerabilities in the country.

1.5 Theoretical framework

1.5.1 Theory and concept relevance to present study

In this thesis, sustainable development (SD) has been reviewed as a focal concept in this study. The SD concept has been recognized as a political and ethical guideline for dealing with ecological and social crises. The concept was first inaugurated in 1987 by the World Commission on Environment and Development (so-called Brundtland Commission). In fact, SD entered onto the global stage in 1992 followed by the 'Earth Summit' in Rio de Janeiro. The United Nations presented SD as their strategic concept for shaping and, indeed, saving the future of the blue planet, and it promised to become the key-word for describing a new balance between use and preservation of nature's potential and resources. The Brundtland Commission, which paved the way to the Rio Summit, defined SD as 'a development that can meet the needs of the present generation without compromising the ability of future generations to meet their own needs' (WCED 1987). Thus, SD is not a choice between environmental protection and social progress, but rather more about striving for economic and social development that would be compatible with environmental protection.

Generally, SD encompasses three fundamental approaches: economic, environmental and social, which are interrelated and complementary (Ciegis et al. 2009). Economic sustainability aims to maximize the flow of per capita income including a basic equity, and to improve the living standards of the local populace. Environmental sustainability pays most attention to the stability of biological and physical systems. The main doctrines are (1) to maintain a sustainable yield and consumption of renewable resources, (2) to reduce environmental pollution, and (3) to prevent depletion of non-renewable resources. However, social sustainability refers to the ability of a community to develop process and structures which not only meet the needs of its current members but also support the ability of future generations to maintain a healthy community (Bohle et al. 1994). It requires certain critical components of social capital: understanding and knowledge to solve social, economic and environmental problems (Berkes and Folke 1994). Nevertheless, bioenergy research is still at a nascent stage in Bangladesh. Few studies have been conducted so far and most have focused on local issues related to supply and consumption of biomass fuel. Hence, the SD concepts on supply and demand of biomass based energy have been considered closely in this study.

1.5.2 Sustainable development relevant to bioenergy development in Bangladesh

Bangladesh is relatively late in introducing the SD concept into national programmes. During the GoB's Fourth Five-Year Plan (1990-1995), the concept of SD was incorporated into the national programmes and was followed by the formulation of the National

Environment Policy, the National Conservation Strategy (NCS), and the National Environment Action Plan (NEAP). Bangladesh signed the Rio Declaration and endorsed Agenda 21 at the UN Conference on Environment and Development in 1992. The first draft of the National Environment Management Action Plan (NEMAP) was prepared in 1995, which was based on commitments made under Agenda 21 (MoEF 1995). NEMAP was considered the first initiative by Bangladesh towards concrete programmes and interventions that supported the SD concept and promoted better environmental management. It identified the key national environmental issues and actions required to halt or reduce environmental degradation, improve the environment, conserve biodiversity, promote SD and improve the quality of human life (Hossain and Tamim 2006). NEMAP recognized the importance of sustainable biomass based fuel development in all regions of the country in order to satisfy household, commercial and industrial energy needs.

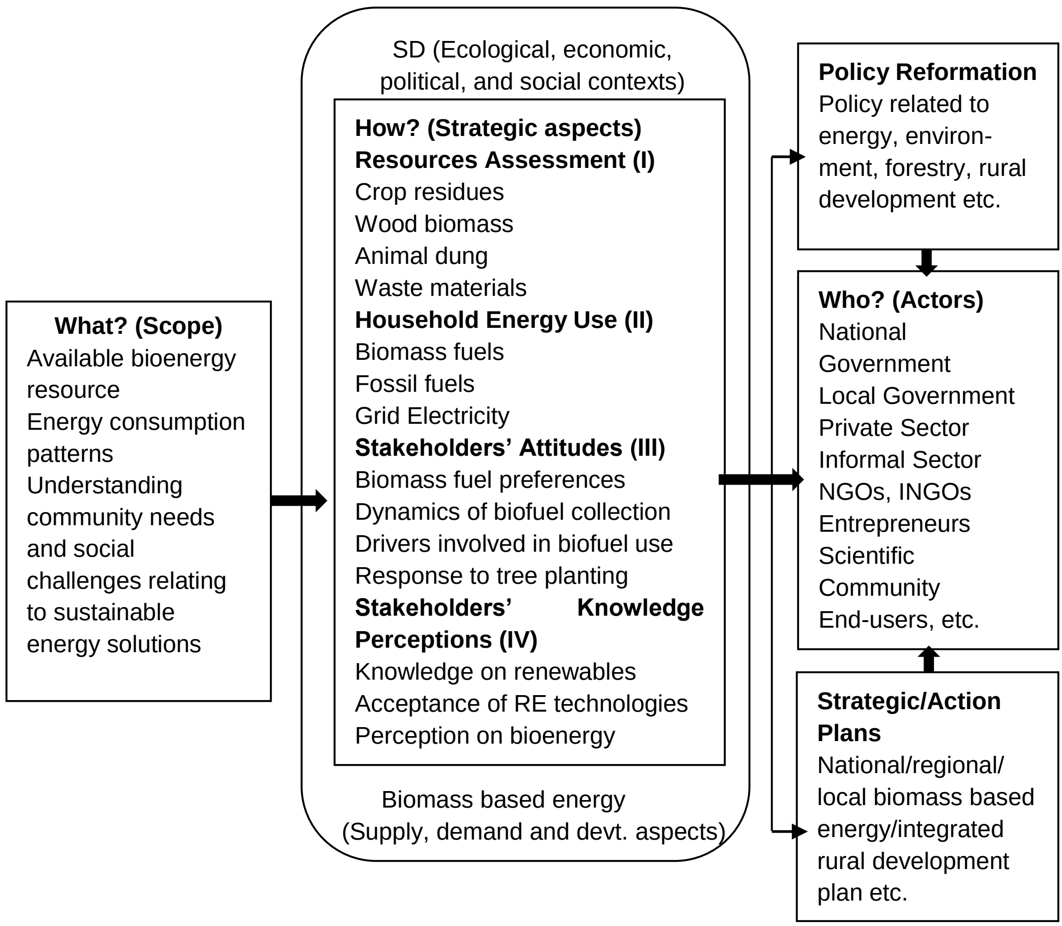

Figure 1. General framework of the study.

At the same time, NEMAP also sought to implement the concept of SD as an alternative approach for the promotion of sustainable livelihoods equitably through the different regions of the country. In addition to NEMAP, Bangladesh's Millennium Development Goals (MDGs) and the World Bank's Poverty Reduction Strategy Paper (PRSP) also focused on the concept of SD. The first MDGs Progress Report was prepared by the GoB and the United Nations in 2005 in compliance with the Rio Declaration. The report set targets up to 2015 and provided a framework or roadmap to achieve most UN MDGs on time (GoB and UN 2005). In contrast, PRSP has wider guidelines for development programmes that aim to achieve the objectives of SD. A recent PRSP was prepared in 2011 under the Sixth Five-Year Plan (FY2011-FY2015) and provided a reasonable discussion on the major environmental issues that affect Bangladesh (IMF 2013). Both the MDGs and PRSP documents argued that biomass fuels constitute the main source of energy supply; however, a heavy reliance upon them in rural areas has resulted in adverse impacts on soil characteristics and on the availability of fodder, fruits, fuels etc.

Bangladesh has taken steps to extend and develop the use of renewables, especially biomass, to ensure future energy security. As a source of primary energy supply, wood-based biomass has been targeted for development in rural areas. For instance, the Forestry Master Plan (FMP) proposed for the period 1993-2013 and involves a reforestation of forests, governmental *khas* (governmental fallow lands), and private lands at a rate of 13500 ha/year (including 3500 ha/year for short rotation plantations, especially for wood fuel) (MoEF 1992). FMP also recognized that public participation was the main driving factor for success of forestry programmes in rural areas. Forestry programmes not only provide opportunities for future sustainable energy supply but also offer other social and environmental benefits. Therefore, the development of wood-based energy has to be managed in line with the principles of SD. The achievement of sustainability in the forestry and energy sectors depends on the active participation of the local communities, as well as their involvement in decision making at different levels (Lunnan et al. 2008; Rio and Burguillo 2009) and in the context of Bangladesh, it is also highly relevant (MoEF 1992; Zaman et al. 2011). Moreover, an assessment of existing resources, current consumption patterns, and public participation in sustainable energy development are considered the key factors that determine future sustainable energy directives (EU 2010). Hence, this study has incorporated the importance of such factors, in combination with the SD concept, in the design of its research strategies (Figure 1).

1.5.3 Assessment of bioenergy resources

As outlined above, biomass fuel constitutes the most significant source of energy supply in Bangladesh. However, due to socio-economic conditions, it has been envisaged that biomass will remain the dominant source of cooking fuels in rural areas (Asaduzzaman et al. 2010). Biomass fuel resources are not evenly distributed in the country. For instance, most of the forested areas are located in the eastern part of the country whereas the western and northern parts are rich in agricultural land. Thus, there is a regional disparity in the type, production and use of biomass fuels, and to a large extent the bioenergy potential in the country remains un-surveyed and unknown. However, some assessment of the renewable and bioenergy potential in the country has been conducted (Islam 2002; Islam et al. 2008; LGED and FAO 2006; Mondal and Denich 2010), although most of the previous studies provided incomplete or insufficient information, which prevented a thorough assessment of bioenergy potential at the national level.

Assessment of energy resources is considered an important aspect for energy planning and development at local, regional, national and global levels (DCENR 2012).

Notwithstanding, resource assessment is a prerequisite for the development and upscaling of any bioenergy project (Milbrandt and Uriarte 2012). In this context, bioenergy resource assessment is crucial to the development of a sustainable energy plan. It could provide a strategic approach for current utilization patterns and for planning the future direction of the development of this resource. Bioenergy assessment is indispensable prior to the implementation of any bioenergy technology in order to minimize negative impacts and to optimize positive impacts on the environment. A recent study showed that bioenergy potential is an important parameter since it determines the approach and methodology in resource management to a large extent (EC 2011). In general, bioenergy resource assessment involves at least three types of potential; theoretical, available and economic (Voivontas et al. 1998).

- *Theoretical potential* refers to the ultimate bioenergy potential based on calculation of all existing biomass that are theoretically available for bioenergy production within fundamental biophysical limits. Theoretical potential often refers to available potential and does not consider constraints on resources access or their cost-effectiveness.
- *Available potential* is the fraction of the theoretical potential that is available under current technological limitations (i.e. harvesting techniques, infrastructure and accessibility, and processing techniques), environmental considerations, policy incentives as well as a number of institutional and social constraints.
- *Economic potential* refers to the part of the technical potential that meets the criteria of economic profitability within given framework conditions. The limit of the economic potential is largely determined by infrastructural, technical and economic constraints. Therefore, the economic potential depends on the costs of biomass resources as well as other competing energy sources.

1.5.4 Determination of household energy consumption patterns

The household sector is considered an important sector for energy consumption worldwide. This sector consumes about 15- 25% of the total primary energy in OECD (Organization of Economic Cooperation and Development) countries and accounts for a high proportion in many developing countries (IEA 2014). However, about 60% of the total primary energy in Bangladesh is consumed by households for domestic purposes, especially for household cooking. The consumption figure is much higher in rural areas (LGED and FAO 2006). Despite an average economic growth rate of 6.7% in recent years, there is still a wide disparity between urban and rural areas in the development and access to modern energy (IMF 2013). For instance, 28% of urban people live under the poverty level whereas in the rural areas the figure is 44% (national average poverty level is 40%). Moreover, 66% of the urban households use biomass for cooking, whereas in rural areas almost all households use biomass for the same purpose (Energypedia 2014).

Consumption of commercial energy, such as grid electricity and gas also varies between urban and rural households. Only 30% of the rural households have access to grid electricity and less than 1% to natural gas (Asaduzzaman et al. 2010). Most of the commercial energy intervention programmes have been focused in urban areas. In contrast, rural areas are mainly targeted for the development of renewable energy technologies, such as solar and biomass energy. Despite the effectiveness of these energy programmes, the overall energy consumption patterns of rural households remain relatively unknown.

Household energy consumption patterns represent the status of welfare as well as the stage of economic development (Reddy 2003). For instance, consumption of the modern form of energy, i.e. electricity, rises with the increase in economic development. In the context of Bangladesh, the rural household sector forms the largest single final primary energy user-group, follows by industrial, urea production and transport sector (LGED and FAO 2006). However, lack of data and knowledge gaps in regard to rural household energy consumption is recognized as one of the obstacles to the development of sustainable energy strategies (Asaduzzaman et al. 2010). Moreover, household energy consumption is expected to increase in the future in rural areas of Bangladesh in conjunction with economic growth and per capita income (IMF 2013). Therefore, comprehensive studies on the energy consumption patterns of rural households are important for energy economics from local to national levels.

1.5.5 Study on rural households' preferences and attitudes towards biomass fuel

Improving access to an affordable and reliable energy supply for household use is an important aspect in energy economics, especially for rural households that predominantly depend on biomass for cooking (Malla and Timilsina 2014). In fact, a number of factors; socioeconomic (accessibility, availability, collection costs, fuel prices, household size, household income, education), attitudinal (awareness, lifestyle), cultural and external (indoor air pollution, government policies, prices of alternative energy sources) determine the preference of biomass fuel (Suliman 2013; Alem et al. 2013). However, in countries like Bangladesh, biomass fuels are overexploited and this has resulted in environmental degradation and resource depletion (Jashimuddin et al. 2006). An empirical study from India suggested that the identification and development of alternatives to biomass fuels is important in order to reduce the biotic pressure from biomass fuel use (Badola 1998). This can be done by either providing a wider range of choices through increased incomes or by providing specific alternatives to forest and other biomass fuels.

Thus, sustainable forest and energy policies need to be incorporated in both supply (through resource development) and demand side management. The formulation of sustainable bioenergy-based rural energy strategies either at regional or national levels requires a detailed and accurate assessment of the range of biomass fuel choice, existing biomass fuel resources, the involvement of end-users and their attitudes towards bioenergy resource development. However, little is known of rural households' preferences and attitudes towards biomass fuels in the context of rural Bangladesh. A few studies have examined various aspects of biomass preferences (Miah et al. 2003; Jashimuddin et al. 2006), yet most have focused either on a specific area or have recorded at the village level. Hence this current study has considered that an investigation of households' preferences and attitudes towards biomass fuels to be one of its main research components.

1.5.6 Investigation on households' knowledge and perception towards bioenergy

The knowledge, perceptions and attitudes of stakeholders in regard to environmental issues are highly important in the development of renewable energy and meeting energy policy targets (Devine-Wright 2007; Liarakou et al. 2009). A number of studies have revealed that such elements have profound roles in the achievement of renewable energy projects, particularly wind and biomass development (Toke 2005; OECD 2010). Recent studies have argued that public knowledge on green energy is still limited (Delshad et al. 2010; Stidham and Simon-Brown 2011; Monroe and Oxarart 2011). Despite a lack of knowledge, the public want to be part of the energy planning process. Knowledge is important when introducing new technologies and helps promote an understanding of sophisticated systems (Giddens 1990). In the context of Bangladesh, public knowledge has been recognized as an important parameter for the development of renewable energy, in meeting national energy policy targets and for the adoption of renewable energy technologies (Islam and Islam 2005; Asaduzzaman et al. 2010). Public perceptions are also crucial for the adoption of renewable energy technologies (Greenberg 2009). Moreover, a study from Uzbekistan revealed that public perception seems to be an important aspect for the penetration of new forms of renewable energy in society (Eshchanov et al. 2011). A recent study from Ireland showed that public perception determines the success of the concept of renewable energy including development strategies, the decision-making process and assuring acceptability (DCENR 2012).

Public knowledge and perceptions are important elements in the development of renewable, and biomass based energy in particular (Ekins 2004; Reddy and Balachandra 2006). Upham and Shackley (2006) found that such elements have a major influence on the energy policy decision-making process. Studies from Greece (Liarakou et al. 2009) and India (Badola et al. 2012) have shown that studies of knowledge, perception and attitudes linked to various environmental issues are worthwhile for the development of renewable energy and conservation of natural forest resources. Contemporary studies from Finland (Halder et al. 2010), China (Qu et al. 2011) and Jordan (Zyadin et al. 2012) have identified that public knowledge, perceptions, and attitudes have a significant role in the development of biomass based energy. However, studies on knowledge, perception and attitudes are a prerequisite for analyzing the value of bioenergy from an end-users' perspective, since such elements influence policy makers in bioenergy project implementation in society (Healion et al. 2005; Greenberg 2009; EC 2011). Although biomass fuel is widely used by rural households of Bangladesh, their knowledge and perception in regard to the development of this fuel is still poorly known. Hence, studies on the knowledge and perception of rural households towards bioenergy is imperative since they represent the main end-user group in the country.

1.6 Aim of the study

There is an urgent need to understand biomass resource availability, consumption patterns, and the knowledge, perceptions and attitudes of the public towards bioenergy for future sustainable energy development, particularly in view of the importance of biomass for the supply of primary energy, government plans to promote sustainable energy, climate change mitigation, local energy supplies, curbing environmental degradation, arresting the depletion of forest resources, and rural development. A lack of sufficient information on various aspects of rural bioenergy has been recognized as one of the main challenges for the development of sustainable energy at the local level.

The goal of this Ph.D. is to provide quality information, which could help in the formulation of strategies for the development of sustainable bioenergy in Bangladesh and other developing countries. The specific aims of this study are as follows:

I. To assess bioenergy potential from major crop residues and wood fuels in Bangladesh (Article I);

II. To analyze cross-sectional variation in energy consumption patterns at the household level in rural Bangladesh (Article II);

III. To investigate rural households' preferences and attitudes towards biomass fuels in Bangladesh (Article III);
IV. To evaluate rural households' knowledge and perceptions of renewables with special attention on bioenergy resources development in Bangladesh (Article IV).

2 MATERIALS AND METHODS

2.1 Study area

The study was conducted in four different agro-ecological zones (AEZs) in Bangladesh. For Article I, the country's production data of major crops and various wood fuels were taken into account for the analysis. However, for Articles II-IV, four *upazilas* (sub-districts) namely Kalaroa *upazila* of the Satkhira district, Nachole *upazila* of the Chapai-Nabwabganj district, Nakla *upazila* of the Sherpur district, and Chakaria *upazila* of Cox's Bazar district were purposely selected for the comprehensive field survey (Figure 2). A total of 32 villages under 14 unions from the four *upazilas* were selected for the surveys for Articles II-IV. A brief description of the physical features of the study areas is provided in Table 2.

The Kalaroa *upazila* is located at the southwestern part of the country, approximately 100 km from the largest single section of 'Sunderban' mangrove forest in the world. The region is predominantly an agricultural area. The Nachole *upazila* is located in the western part of the 'Barind Tract' and the region is characterized by an undulating landscape, warm temperatures, low rainfall, low tree cover, and is drought prone. The nearest sal forest (tropical deciduous forest) is approximately 75 km away. The Nakla *upazila* is located in the central-northern part of the country, approximately 40 km from the hill forest areas (tropical evergreen forest) of the Sherpur district. The Chakaria *upazila* is located in the south east of the country. This *upazila* is rich in forest resources (tropical semi-evergreen forest) of which about 5082 ha land is designated as forest land.

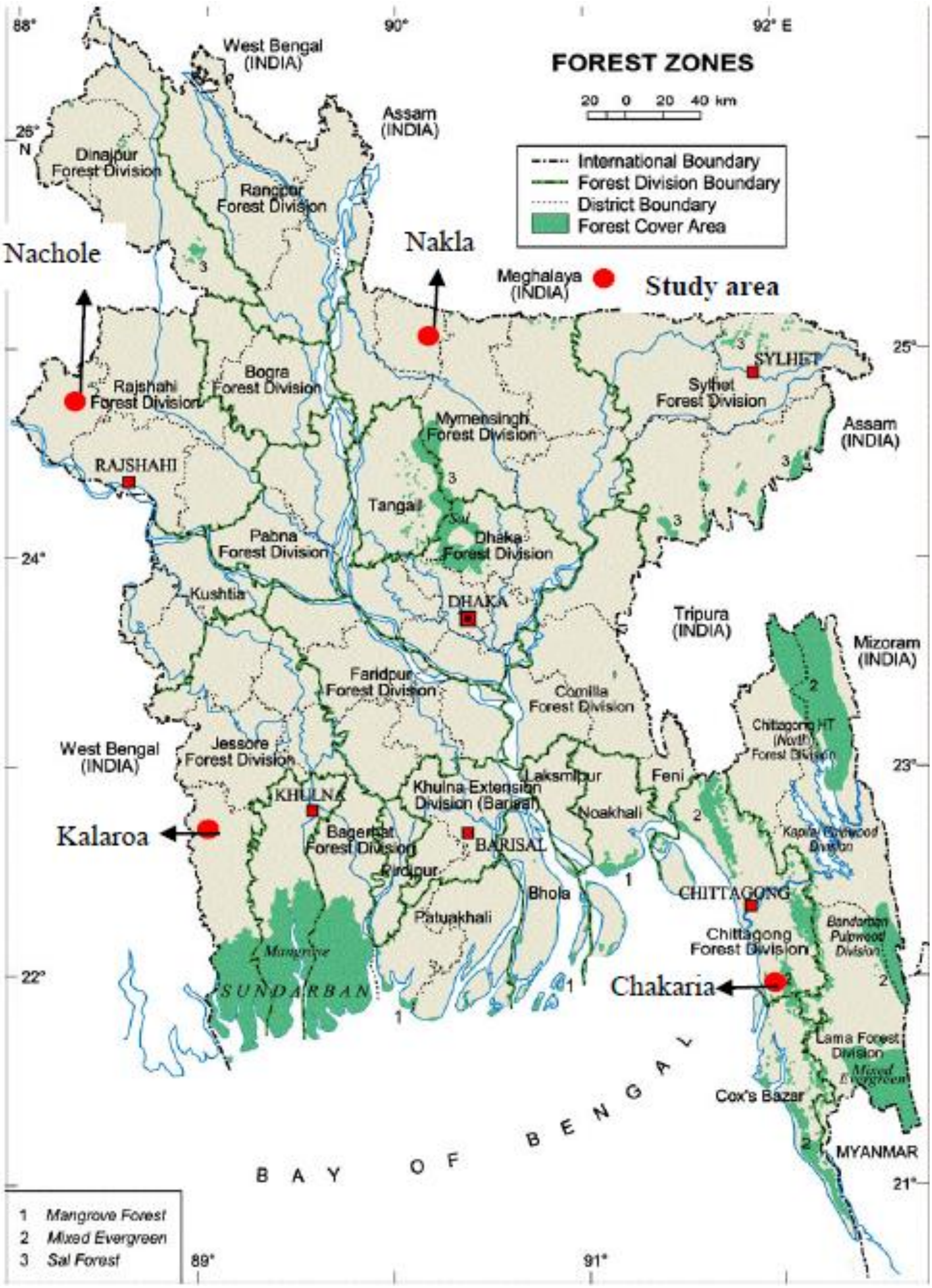

Figure 2. Map of Bangladesh; green colors and red spots indicate the forest area and field survey areas, respectively.

Table 2. Description of the study areas and selected unions and villages used in the household survey

Name and AEZ Classification ID	Physical characteristics	District	*Upazila*	Union	Village	Remarks
High Ganges River Floodplain (AEZ ID 11)	Soil types are calcareous alluvium. Major crops are rice, jute, sugarcane, and oil seed. Climate is tropical monsoon. Annual rainfall ca. 220 cm	Satkhira	Kalaroa	Jalalabad	Jalalabad, Shankarpur	Article III-IV
				Chandanpur	Chandanpur, Hizoldi	Article III-IV
				Sonabaria	Uttar Sonabaria, Madra	Article II
				Koila	Alaipur, Koila	Article II
Level Barind Tract (AEZ ID 25)	Soil types are terrace, low moisture. Major crops are rice, oil seeds, and sugarcane. Climate is sub-tropical monsoon. Annual rainfall ca. 80 cm.	Chapai-Nabwabgang	Nachole	Kashba	Kendobona, Bailkapur	Article III-IV
				Nachole	Banipur, Darbeshpur	Article III-IV
				Nezampur	Tikoil, Bansbaria	Article II
				Fatipur	Takahara, Amlaine	Article II
Old Brahmaputra Floodplain (AEZ ID 9)	Soils are silt loams. Major crops are rice, jute, wheat, sugarcane. Climate is a mixture of tropical & subtropical monsoon. Annual rainfall ca.170 cm.	Sherpur	Nakla	Banesherdi	Banesherdi, Polardeshi	Article III-IV
				Ganapardi	Khrisnapur, Gajaria	Article III-IV
				Chandrakona	Bandatiki, Huzurikanda	Article II
				Talki	Bibirchar,Shailampur	Article II
Chittagong Coastal Plain region (AEZ ID 21)	Soil types are non-calcareous, grey alluvium, acid sulphate, and unsuitable for crop cultivation. Climate is tropical monsoon that consists of a long rainy period and a short winter. Annual rainfall ca. 350 cm.	Cox's Bazar	Chakaria	Illishia	Chuarphari, Darbeshkata	Article III-IV
				Badarkhali	Mongpara, Northpara	Article III-IV
				Badarkhali	Eastpara, Westpara	Article II
				Illishia	Darbeshkata, Darbeshkata	Article II

2.2 Data sources

The systematic approach used in this study is shown in Figure 3. In Article I, the country's major agricultural crop (i.e. rice, jute, wheat, sugarcane, mustard, coconut and lentil) production data (1990-2009) were collected from Bangladesh Bureau of Statistics (BBS 2010; BBS 2009a; BBS 2009b). The FAO's (Food and Agricultural Organization of the United Nations) FAOStat database was explored to gather forest products (i.e. saw logs and veneer logs, plywood and split logs, pulpwood and particleboard, and firewood) production data for the period 1990-2009 (FAOStat 2009). The data were cross-checked with interviews with various experts in the corresponding departments and organizations.

For Articles II-IV, the primary data were collected through door-to-door household surveys. Either the head of the household or an adult representative of the sampled households were interviewed using structured questionnaires that consisted of both open- and closed-ended items. Readers interested in the questionnaires used in this study are referred to the appendices (Appendix AI-AIII) of this thesis. The interview was based on memory recall, knowledge and understanding of the respondent to the relevant question of a specific questionnaire.

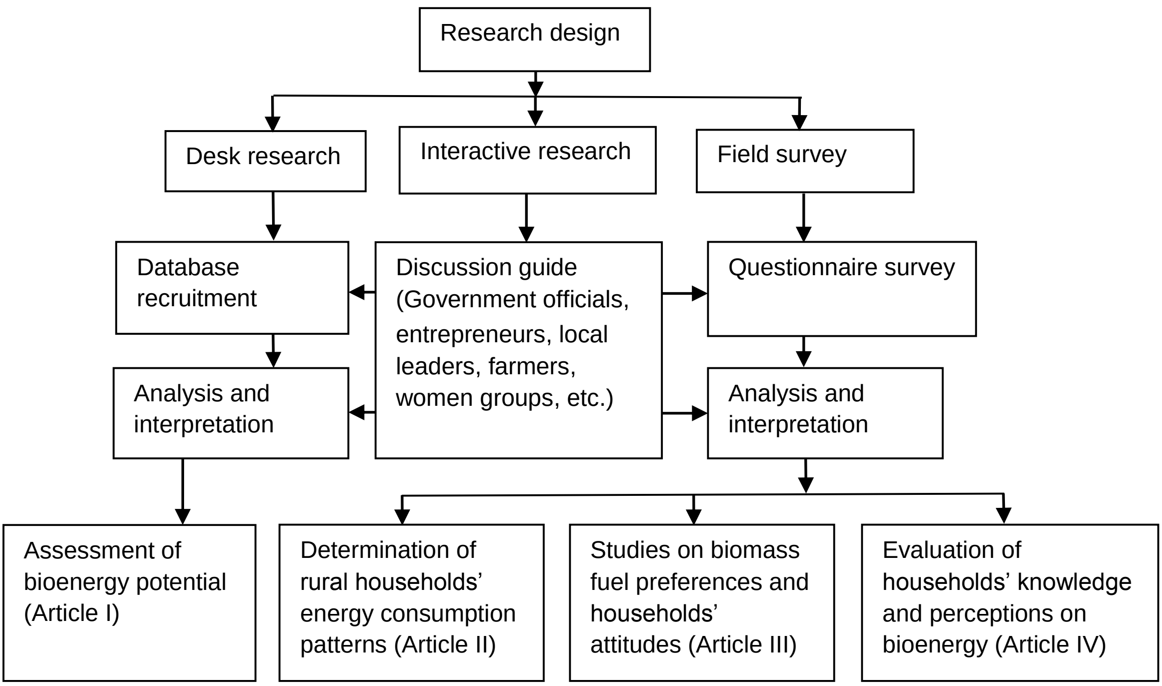

Figure 3. Layout of data gathering for the study.

2.3 Estimation of bioenergy potential from crop residues and wood fuels (Article I)

Crop residues are the most comprehensive and most readily available source of energy for domestic use in rural areas of Bangladesh. Available residues were identified as rice straw, rice husk, and rice bran, wheat straw, jute stalk, sugarcane bagasse and molasses from trimmed sugarcane, mustard straw, coconut shell and husks, and lentil straw. In this study, three steps were followed to determine the bioenergy potential of the crop residues. In the first step, quantities of the residues were determined by applying a residual factor and a corresponding utilization coefficient to crop yield (Table 1, Article I). In the second step, an availability fraction determined the amount of residue that was considered as available potential for energy use. It was assumed that 50% of rice crop residues and 20% of non-rice crop (wheat, jute, sugarcane, mustard, coconut and lentil) residues were used for non-energy purposes, and these values were cross-checked through discussion with farmers in the field. Calculated residues were subsequently subtracted in a semi-quantitative manner with a number of reduction factors directly or indirectly related to non-energy purposes, such as animal feeding, roof thatching, fencing, mulching, and fertilizer use. Reduction factors that were successively applied varied with crop types, the environment and assumptions on the level of inputs/management regime. Notwithstanding, 50% of the rice crop residues and 80% of the non-rice crop residues were considered recoverable and could be used for energy purposes. In the third step, available recoverable residues were converted into energy units GJ. The LHV (lower heating value) of selected crop residues and wood fuels were considered in the calculation (Table 2, Article I).

Bioenergy potential from wood fuels was mainly calculated based on the available wood residues from timber logs (sometimes called round wood logs) and the production of firewood. In this study, 43% of the log input for saw logs and veneer logs, 47% of the log input for plywood and split logs, and 5% of the log input for pulp and particle board were considered as wood residues (Table 4, Article I). Recoverable quantities of wood residues, as well as firewood, were then multiplied with a common wood density factor (0.57) and converted from the measurement unit m^3 (cubic meter) to t (metric tonnes). The mean wood density (tonnes/m^3) for most common tropical tree species in tropical Asia has been reported as 0.57 tonnes / m^3 (FAO 2001). The recoverable amount of wood residues and firewood were then converted into available energy units GJ/t. In this analysis, the energy content of all wood residues and firewood at LHV was considered as 15 GJ/t.

In this study, there were four scenarios: a ‘status quo’ benchmark or trend scenario and three alternative scenarios, constructed to project bioenergy potential from major crop residues and wood fuels through to 2020. The benchmark or trend scenario was based on the average annual growth of each individual crop and forest product from the period of 1990-2009. Alternative scenario 1 was based on the average national GDP growth in the crop and forestry sub-sectors (both are under the agriculture sector) from 1999 to 2009, whereas alternative scenarios 2 and 3 were based on expected moderate and higher GDP growth respectively in the agriculture sector as forecast by the government’s MDGs (Table 5, Article I).

2.4 Survey procedure and data collection (Articles II-IV)

The studies (Articles II-IV) involved a socio-economic survey among rural households in the four selected *upazila*s. The survey was based on a three-stage stratified random sampling technique where the union (administrative unit) of the *upazila* was the first-stage sampling unit, the villages of the union were the second-stage sampling unit, and the households of the villages the third-stage. Socio-economic information, such as the number of households in the village and their income were obtained from the local '*union parishad*' (local governmental administrative unit) office. Based on their monthly income, the households of the selected village were broadly categorized into three socio-economic groups: rich (household monthly income more than 12000 BDT or $150), middle class (household monthly income between 6001-12000 BDT or $75-150), and poor (household monthly income less than 6000 BDT or $75). On the basis of households' socio-economic status, a total of 15 households (five households from each socio-economic group) from each village were randomly selected. After the selection of households, the locations of households were identified with the help of local volunteers. For each Article, 240 household respondents from 16 villages under four *upazila* were selected for the questionnaire surveys. Thus, a total 720 household respondents from 4 *upazilas* were interviewed for Articles II-IV. The average households' sampling intensity for Articles II, III and IV was 5.6, 6.2 and 6.3% respectively. Typically, a 5% sample size is considered to be acceptable for large-scale household surveys (UN 2005).

2.5 Estimation of household energy consumption (Article II)

Data on household energy consumption patterns were collected through a questionnaire survey. The data on the various energy fuels categories were recorded using different physical units, for instance kilogram (kg) for biomass and candle, liter (l) for kerosene and LPG (liquefied petroleum gas), and kilowatt hour (kWh) for grid electricity. The amount of biomass used by the households was crosschecked through spot measurements with the help of the volunteers, as well as from members of the respective households. In those cases, the households were asked to provide information as to how much biomass fuels they intended to use for daily household purposes. The quantities of the various biomass fuels were measured and subsequently, the respective households were further interviewed the following the day to determine the actual quantity of biomass fuels used. A total of 24 household respondents (10% of the sample size) were subjected to a spot measurement.

In the first step of the analysis, the energy content of the various energy fuels were converted into a uniform physical unit MJ (mega joule). In this study, the energy value per unit of electricity, kerosene, LPG and candle were considered as 3.6 MJ/kWh, 37.6 MJ/l, 26.0 MJ/l, and 42.0 MJ/kg, respectively. The LHV of the various biomass fuels was applied in the calculation. In this study, the LHV of firewood, leaves and twigs, bamboo, rice husk, rice straw, jute stalk, other crop residues, and cow dung were considered as 15.0, 12.5, 15.0, 12.76, 12.24, 12.76, 12.6 and 11.6 MJ/kg, respectively. In the next step, the calculated total of consumed primary energy and bioenergy were converted to a single energy unit GJ, and subsequently divided by the number of family members to reach a per capita primary energy and bioenergy consumption value.

2.6 Determination of households' preferences and attitudes towards biomass fuels (Article III)

For this research, the household survey was conducted with both closed-ended and open-ended questionnaires that consisted of two sections. In the first section, questions were designed to explore general information and to identify preferred biomass fuels. Respondents were asked to provide information on their educational level, occupation, types of biomass fuels used, preferred biomass fuels, preferred firewood species, methods of biomass fuel collection, types of difficulties faced during collection etc. In the second section, questions were related to the attitudes of the respondents towards afforestation programmes that were initiated to meet the future biomass fuel demand. In addition, respondents were asked about their involvement in tree plantations, their willingness to support afforestation programmes, their expectations from governmental afforestation programmes, as well as their views on the implementation of such afforestation programmes in their respective areas.

2.7 Evaluation of households' knowledge and perceptions on renewable energy (Article IV)

An evaluation of households' knowledge and perceptions on renewable energy was performed through a questionnaire survey. The survey instrument consisted of both open-ended and close-ended (multiple choice and 5-point Likert-type) questions. The questionnaire had six sections. The first section contained socio-demographic data of the respondents; the second section mainly focused on the knowledge of different RES, such as solar, wind, hydro and biomass, the third section concentrated on the various types of biomass fuels, such as wood fuels, crop residues, cow dung, briquette, biogas and biodiesel. Questions in the fourth section were related to the respondents' attitudes towards the domestic use of solar and improved biomass fuels, such as biogas and briquettes, whereas, in the fifth section questions were related to the respondents' attitudes towards the installation of an improved oven as a response to energy efficiency and climate change related issues (reduction of greenhouse gas emissions). The final section consisted of 10 questions that explored the respondents' perceptions on different facts related to the environment and the development of bioenergy. Questions related to knowledge were categorized into *low*, *medium* and *high* levels to measure a respondents' cognitive knowledge about RES and bioenergy in particular. Moreover, a 5-point Likert-type question was applied as an instrument for structuring and analyzing the answers in this section. Likert-type questions were scored from 1 to 5 where 1 denoted *strongly disagree*, 2 *disagree*, 3 *do not know*, 4 *agree* and 5 *strongly agree*.

2.8 Data analysis

Data (Articles I-IV) analysis was accomplished by using SPSS 19.0 (IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp.) and Microsoft Excel software. Simple descriptive statistics were used to analyze and structure the data for Article I. In Article II, descriptive statistics, One-way ANOVA and Pearson correlation tests were applied to explore the differences and relationships between variables. Finally, a linear regression model was constructed to show the relationship between households' bioenergy consumption and different socio-economic parameters. Data for Articles III-IV were analyzed using descriptive statistics, One-way ANOVA, and the post hoc Tukey test to determine the average rating of the different statements of the respondents, and to compare mean differences between variables. In addition, a Principal Component Analysis (PCA) was performed for the 10-item Likert-type questions in Article IV in order to reveal their internal structures and to find out whether some of them would indicate respondents' perceptions towards various aspects of biomass fuels. Finally, Bivariate and Reliability (Cronbach's Alpha test) analyses were applied to find out the MIC (mean inter-item correlation) and reliability of the identified key components of the Likert-type questions respectively. In this study, the overall reliability of the 10-item 5-point Likert-type questions reached a satisfactory level of internal consistency (α=0.69). In general, a reliability coefficient of 0.70 and above is desirable for consistency levels (Halder et al. 2010).

3 RESULTS

3.1 Bioenergy potential

3.1.1 Estimated bioenergy potential from crop residues and wood fuels

The study examined the bioenergy potential from major crop residues and wood fuels, which are recognized as the most readily available biomass based energy sources in the rural areas of Bangladesh. In terms of production, the major agricultural crops were identified as rice, jute, wheat, sugarcane, mustard, coconut and lentil. These crops generate a considerable proportion of the residues that are used for both energy and non-energy purposes. Crop residues, such as rice straw, rice husk and rice bran, wheat straw, jute stalk, sugarcane bagasse, sugarcane molasses, mustard straw, coconut husk, coconut shell, and lentil straw were observed to be used for energy purposes. Crop residues were recognized as the most promising source of biomass fuel in rural areas of Bangladesh. The total estimated gross production of crop residues from all selected crops amounted to 79.19 million tonnes in 2009 of which 41.56 million tonnes were assumed to be available for energy use. The estimated recoverable bioenergy potential from all selected crop residues was 525.89 million GJ in 2009 (Figure 4). Rice was ranked the highest in terms of potential bioenergy production in Bangladesh. Since 1990, rice production has steadily increased at an annual rate of 3.2%. Rice straw constituted the single largest source of bioenergy with an estimated recoverable bioenergy potential of 383.32 million GJ in 2009. Rice straw was by far the most important agricultural residue and accounted for 79% of total gross crop residues production and accounted for 73% of the total recoverable bioenergy potential from all the selected crops. In contrast, the estimated recoverable bioenergy potential from rice husk, sugarcane bagasse, and wheat straw were 47.95, 21.85 and 21.28 million GJ, respectively at 2009 levels.

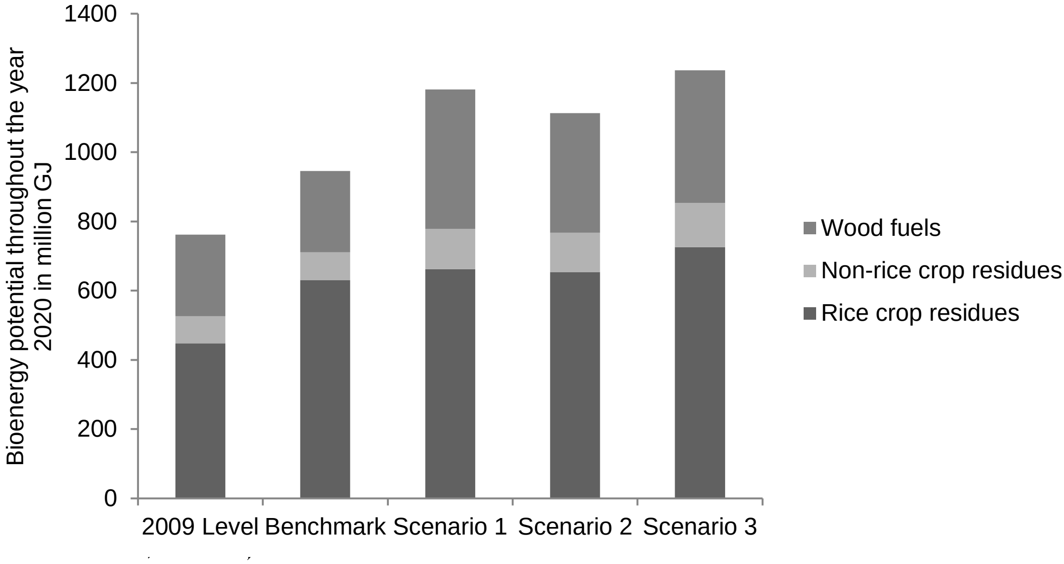

Figure 4. Bioenergy potential from selected crop residues and wood fuels at 2009 levels and under different scenarios.

The bioenergy potential from wood residues was only 2.41 million GJ, but was considered to be highly significant by some consumers, particularly in the urban areas of Bangladesh. Statistics showed that since 1990 the production of round wood has gradually declined, and, therefore, the availability of wood residues was assumed to be in decline. Homestead forests, government plantations and forests were observed to be the main sources of firewood supply in the rural areas of the country. Since 1990, firewood production in the country has remained unchanged at 16 million tonnes annually. The estimated bioenergy potential from firewood was 233.92 million GJ in 2009, which constituted over 99% of the total wood energy potential of the country. The availability of wood fuels varied considerably from region to region.

3.1.2 Predicted bioenergy potential from crop residues and wood fuels

The bioenergy potential from selected crops and wood fuels under the benchmark and three alternative scenarios are presented in Figure 4. Under the benchmark, bioenergy potential from all selected crops was predicted to reach 711.27 million GJ by 2020 (Table 7, Article I). Residues from rice production were recognized as the major contributors. The recoverable bioenergy potential from rice residues could increase from 447.55 million GJ in 2009 to 630.86 million GJ by 2020, 41% higher than that the 2009 level. Recoverable bioenergy potential from non-rice crop residues could not strongly increase under benchmark (from 79.19 million GJ in 2009 to 80.41 million GJ by 2020). However, the bioenergy potential from wood fuels may decrease over time under the benchmark at a rate of 1% annually in comparison to 2009 levels. The potential from wood fuels could drop to 234.34 million GJ by 2020.

The study predicted that the maximum bioenergy potential from selected crop residues under the alternative scenarios 1, 2 and 3 would be reached at 778.45, 767.78 and 853.43 million GJ, respectively, which is 9.4, 7.9 and 20% higher than that of the benchmark, respectively. Rice straw and rice husks were also identified as the most promising residues for bioenergy under all three alternative scenarios. However, the maximum bioenergy potential from wood fuels under the alternative scenarios 1, 2, and 3 would be reached at 403.36, 345.03 and 382.95 million GJ, respectively; which is 72.1, 47.2 and 63.4% higher respectively than that of the benchmark.

3.2 Rural households' energy consumption patterns

3.2.1 Fuel types and consumption patterns

The study showed that rural households use biomass, grid electricity, kerosene, candles and LPG for their daily energy requirements. Biomass constituted the predominant source of energy supply in the study areas. All surveyed households were reported to use different types of biomass fuels for their household purposes, especially for cooking. In addition to biomass fuels, 98% of the households used kerosene, 56% used grid electricity, 10% used candles and only 4% used LPG. The monthly average household consumption of biomass fuels was 219 kg. However, the estimated monthly average household consumption of non-biomass fuels, such as kerosene was 2.39 liters, electricity 29.63 kWh, candles 0.04 kg, and LPG 0.27 liters (Table 3, Article II). Choice of fuel selection and consumption varied considerably between rich, middle, and poor households.

It was observed that the consumption of biomass fuels depended on their availability at local levels. Monthly average household consumption of different biomass fuels, such as firewood, leaves & twigs, bamboo, rice straw, rice-husk, jute stalk, other crop residues and cow dung amounted about 94, 59, 4, 2, 8, 7, 8, and 37 kg, respectively (Table 5, Article II). Although the availability of rice straw is more frequent in rural areas, it was only used in small quantities as a daily cooking fuel due to poor fuel quality. In contrast, rice-husk was used mainly for animal feeding, aquaculture, and for commercial purposes such as briquette making. The non-energy use options restricted rural households to the use of rice-husk as their daily cooking fuel. Nevertheless, home gardens (so-called village forests), trees on governmental marginal lands, and secondary plantations were identified as the main sources of firewood supply in Kalaroa, Nachole and Nakla regions, whereas the government forests (both state forests and secondary plantations) were the main sources of firewood in the Chakaria region. Moreover, agricultural farms were the main source of non-wood biomass fuels in all regions.

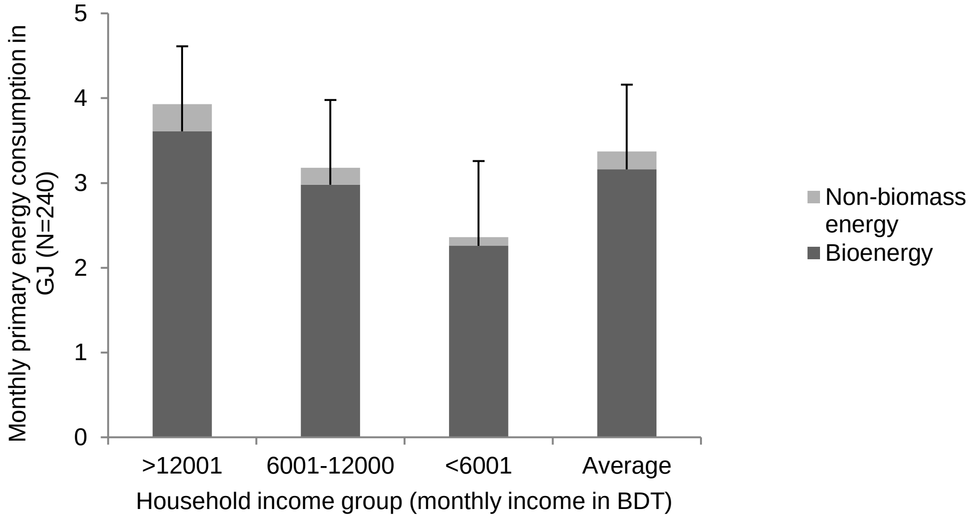

Figure 5. Monthly primary energy consumption (GJ) by socio-economic household groups.

The average household total primary energy and bioenergy consumption was 3.16 GJ/month and 2.95 GJ/month respectively. The consumption of total primary energy and bioenergy varied between socio-economic groups. For instance, the average primary energy consumption among rich, middle-class and poor households was 3.93, 3.18 and 2.36 GJ/month respectively, whereas the average household bioenergy consumption was 3.61, 2.98 and 2.26 GJ/month respectively (Figure 5). However, the average primary energy and bioenergy consumption among rural households was estimated at 0.54 GJ/person/month and 0.50 GJ/person/month respectively. The annual per capita primary energy consumption of rural households' was 6.45 GJ of which the share from biomass fuels was 6.03 GJ. This indicated that energy consumption among rural households of Bangladesh is still at the subsistence level and is based substantially on available biomass fuels.

The study revealed that biomass fuels constituted 93% of the primary energy supply among rural households. Commercial fuels accounted for the remaining 7% of household energy, of which 3.5% was from grid electricity, 3% from kerosene, and 0.5% from candles and LPG. With the exception of LPG, all commercial fuels were used for lighting and to some extent the powering of household appliances. An average of 88% of the biomass fuels was used for cooking, 10% for rice parboiling, and the remaining 2% for jaggery and other household heating purposes.

3.2.2 Socio-economic aspects of energy consumption

This study showed that rural households spent about 5% of their income meeting their primary energy demand. Rich households spent nearly twice as much on energy supply than poor households. The monthly average household energy expenditure for rich, medium and poor households was 736 BDT ($9.6), 500 BDT ($6.5), and 284 BDT ($3.7) respectively. There was a significant relationship (R = 0.66) between household income and household energy expenditure, which indicated that households with higher incomes consumed more energy (Section 3.9, Article II). There were significant differences in the primary energy expenditure among socio-economic groups, however, no significant differences were observed in regard to biomass fuels expenditure (Section 3.8, Article II). The study also showed that there were significant negative relationships between biomass expenditure and the households' homestead area, and between biomass fuel expenditure and the households' landholding. This indicates that the households that own bigger homesteads and large agricultural lands collect the maximum amount of biomass fuels from their own farms. Therefore, they do not need to pay for biomass fuels resulting in less expenditure for this fuel.

Different socio-economic parameters influenced primary energy and bioenergy consumption among rural households. Such parameters include household family size, household income, homestead area, agricultural land, educational status, and housing type. Based on different socio-economic parameters, the study constructed an empirical model for monthly household bioenergy consumption. The model appeared to be highly significant ($R^2 = 80$; $p < 0.01$) and provided an estimation of the coefficients of different household demographic parameters, such as the number of family members, per capita monthly income, per capita homestead area, and per capita agriculture land, most of which determine the household monthly bioenergy consumption in rural areas of Bangladesh. In the model, number of family members was recognized as the most important parameter and explained the highest variation in the model output. While computing step-wise differences, the model suggested the exclusion of two parameters, namely, per capita homestead area and per capita agriculture land from the set of parameters. It indicated that while the inclusion of these two parameters in the model was important they do not sufficiently influence household bioenergy consumption.

3.3 Rural households' preferences and attitudes towards biomass fuels

3.3.1 Commonly used and preferred biomass fuels of rural households

Biomass fuels in the study areas were firewood (which mainly consisted of branch firewood and stem firewood), leaves and twigs, bamboo, rice husk, rice straw, jute stalk, agricultural residues, cow dung, rice-husk briquettes and saw mill residues. The most commonly used biomass fuels were branches, leaves and twigs, cow dung, whereas the most preferred biomass fuels were identified as branches, stem wood, and cow dung (Figure 6). The selection of biomass fuels by the households varied between regions and between socio-economic groups. It was found that biomass fuel selection depended on the availability of the resources in the environment of the household. For instance, in the Chakaria region there is a large area of government forest where most of the households sourced their firewood. However, in the Nachole region, a lower number of the households used firewood and/or used firewood less frequently due to a lower forest cover and a limited supply of firewood.

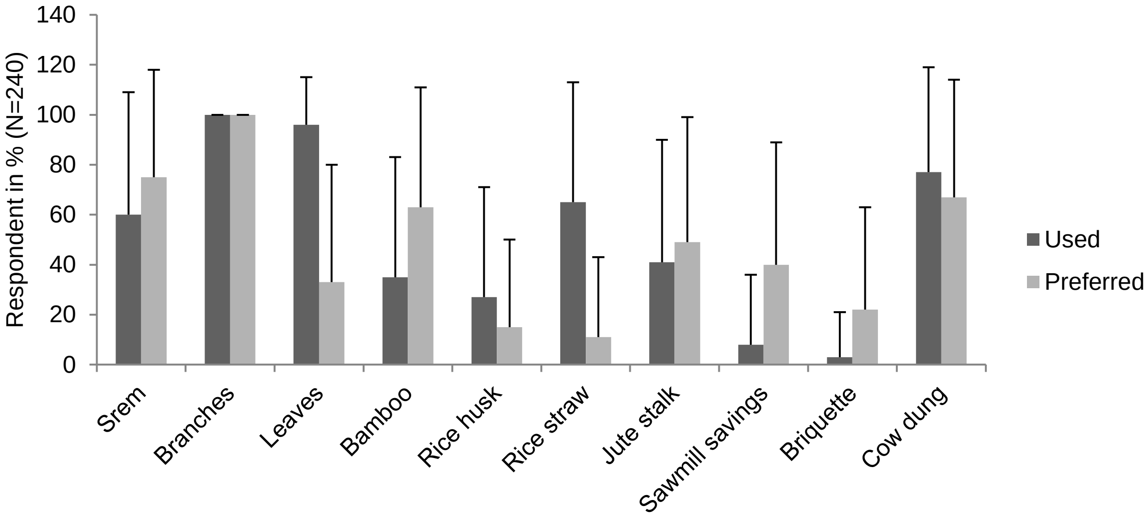

Figure 6. Commonly used and preferred biomass fuels among rural households.

Firewood constituted the most preferred biomass fuel. Rural households used either chopped stem and/or lopped branches as firewood. Approximately 25 tree species were identified as preferred firewood species, of which *Samanea saman*, *Albizia procera,* and *Dalbergia sissoo* were the most popular (Table 4, Article III). Of the 25 preferred firewood species, about 21 species were found on homestead land, 16 species on marginal lands (i.e. land along roadsides, railways and embankments), and 12 species on governmental forests. Typically, marginal lands and *khas* lands (i.e. government unleased lands) were exploited for secondary plantation forests. In addition, some of the richer farmers cultivated small-scale (< 0.5 ha) block plantations on their own lands, mainly with *Swietenia mahagoni*, *Tectona grandis* and *Samanea saman*, for both timber and firewood production purposes as well as for income generation.

3.3.2 Rural households' attitudes towards tree planting

As firewood constituted the most preferred cooking fuel among rural households in the study areas, the supply of this fuel has become an important issue in the view of sustainability. The gradual decline of firewood availability from both homestead and government forests were the main concern in terms of sustainable supply of this fuel. Promotion of tree planting on both on-farm and off-farm lands to meet the firewood and timber demands of the villagers was endorsed by the majority of the household respondents. The study revealed that about 70% of the household respondents planted trees on their farm lands during the last 6 years, while only half of them planted trees within the last 3 years (Table 8, Article III). The numbers of on-farm *tree planters* (in this study, a tree planter was considered a person who planted at least one tree each year during the last 3 years) varied between regions and between socio-economic groups. However, 85% of the respondents supported off-farm tree planting on government owned marginal lands and *khas* lands. The results suggested that tree planting on off-farm lands is becoming popular among rural households since such afforestation may provide firewood supply and additional income to the rural households in their local environment. However, the attitudes of the respondents towards tree planting on off-farm lands varied significantly between regions and between socio-economic groups. The majority of the rich households argued that off-farm tree planting might cause problems for crop cultivation, while middle and poor households claimed that such tree planting programmes might cause a land blockade and could generate social conflicts.

Over 90% of the respondents expressed some sort of expectations from the off-farm afforestation programme on government lands. The expectations were expressed in terms of better timber and firewood supply, financial support, environmental services, training, and employment. The study found that 26% of the respondents received benefits from the previous governmental afforestation programme of which 13% received benefit in terms of firewood supply, 11% received training and employment, and a small number received financial supports. The types of benefits received by the household respondents varied between regions and between socio-economic groups.

The study noted that only a few households or a segment of the local community received benefits from governmental afforestation programmes. In other words, the majority of the rural households did not receive any benefits from governmental afforestation programmes, therefore, community oriented forestry programmes could be important in the development of energy economics in rural areas. Lack of information on afforestation programmes among rural households, lack of motivation, and lack of communication between afforestation implementing agencies and local communities were identified as the main impediments to popularizing afforestation programmes in the study areas. Nevertheless, 86% of the respondents expressed their concerns in regard to the necessity of governmental afforestation programmes in their regions. The results showed that the expectations of households of future firewood supplies from governmental afforestation programmes were high and need to be taken into consideration.

3.4 Rural households' knowledge and perceptions towards sustainable energy development

3.4.1 Households' knowledge on RES and different biomass fuels

The study revealed that households' knowledge of various RES, such as solar panels (so called photovoltaic (PV) panels), wind power, and hydro power fell between the low and medium categories. Figure 7 represents rural households' knowledge on different RES. In regard to solar energy, only 10% expressed that they had a high level of knowledge. Knowledge of solar panels varied between regions, between socio-economic groups and between levels of education. However, none of the households showed a high level of knowledge in regard to the scientific process that underpins the generation of energy from the wind, or the advantages and disadvantages of wind power generation. Most of the households' (88%) possessed a low level of knowledge on wind power. Likewise, in the case of hydro power, only a few households had a high level of knowledge. About 99% of the households were not familiar with the scientific mechanisms for producing energy, whereby a hydraulic turbine converts the energy of flowing water into electricity. Households' knowledge of wind and hydro power varied between socio-economic groups

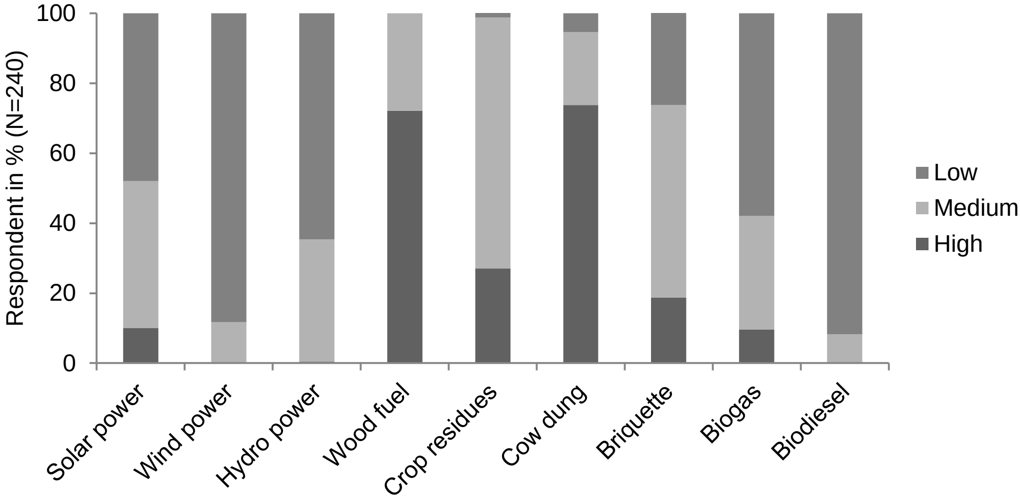

Figure 7. Rural households' knowledge on different renewables in the study area.

and between levels of education. Nevertheless, the results clearly showed that the majority of rural households had limited knowledge in regard to solar, wind and hydro power.

Rural households demonstrated a high level of knowledge of traditional biomass fuels, such as wood fuels, crop residues and cow dung. They were familiar with the production systems, mechanisms of utilization and possible conflicts with food production systems. About 54% of the households possessed a high level of knowledge of the various types of biomass fuels. The level of knowledge of wood fuel and cow dung among rural households was relatively high; medium for briquettes and rather low for biogas and biodiesel (Figure 7). Households' knowledge of biomass fuels varied between regions, between socio-economic groups, and between levels of education (Table A.1, Article 4).

3.4.2 Households' attitudes towards acceptance of renewable energy technology

It was found that nearly 7% of the rural households adopted renewable energy technologies, such as PV panels, biogas plants and improved biofuels for their domestic usage. Only 2% of the households (five households, of which three were from Chakaria, one from Kalaroa, and one from Nachole *upazila*) installed solar panels, and another 1% (three respondents from Nachole *upazila*) built biogas plants. Aside from solar panels and biogas plants, 4% of the households (ten households, of which four were from Kalaroa, one from Nachole, one from Nakla, and four from Chakaria *upazila*) reported that they used rice-husk briquettes as an additional fuel for domestic cooking. Installation of solar panels, biogas plants, and the use of briquettes as fuel were restricted to rich and middle-class households.

In regard to acceptance of new renewable energy technologies and energy efficiency, about 28% of the rural households had installed improved stoves for their domestic cooking. Installation of improved stoves varied between regions, between socio-economic groups and between levels of education. About 49% of the rich, 22% of the middle-class and only

9% of the poor households had installed improved stoves. Furthermore, the installation of improved stoves was higher among households that had a good level of education, while the trend of installation was downward among illiterate households.

Nearly two-thirds of the households answered that they were not able to install improved stoves. About half of them stated that they were not aware of the advantages of improved stoves. Other cited hindrances to the widespread acceptance of improved stoves included a lack of contacts with responsible agencies, the unsuitability of the existing model of improved stove for using locally available traditional biomass fuels, prohibitively high installation costs, lack of services for repairs and maintenance of improved stoves, and unwillingness of households to install the improved stoves. For the latter, households were reluctant to install improved stoves as they felt more comfortable cooking in an open shaded or semi-structural kitchen area where the installation of an improved stove was not possible.

3.4.3 Households' perceptions on bioenergy development

The study applied a 10-item Likert-type questionnaire to evaluate rural households' perceptions on different environmental facts and the development of bioenergy (Table 3, Article IV). About 63% of the households *agreed* (sum of *strongly agree* and *agree*) that all types of biomass fuel resources, including wood-based biomass have declined in their area over time (Item no. 1-2). Although biomass fuel is widely used as a cooking fuel by rural households in the study areas, nearly half of households were not aware of the environmental benefits from using this fuel, which would indicate that there is still a lack of environmental awareness in these communities (Item no. 3). However, the majority of households claimed that the existing afforestation programmes were not sufficient for a sustainable supply of firewood (Item no. 4).

About 66% of the respondents stated that there were still sufficient available lands in their local areas where afforestation programmes could take place (Item no. 5). In fact, governmental departments and local authorities are mostly responsible for implementing afforestation programmes in rural areas, and are seldom assisted by non-governmental organizations. About 98% of the respondents expressed the view that governmental agencies and local leaders could play leading roles in implementing afforestation programmes on available lands in their area (Item no. 6). About 97% of the respondents explicated that there were concerned about future biomass fuel supply (Item no. 7) due to the continuous depletion of biomass fuel resources, lack of adequate afforestation programmes and other environmental degradation issues. Another prominent challenge for biomass fuel resources development was identified as a lack of societal awareness in regard to future biomass fuel supply (Item no. 8). The majority of respondents considered that the introduction of SRF (short-rotation forestry) (Item no. 9), and the enhancement of improved biofuel technologies could be better options (Item no. 10) for a sustainable biomass fuel in the future, especially firewood supply. Nevertheless, the perception of rural households in relation to various facts on bioenergy development varied between the regions (Table A.2, Article 4).

However, PCA pooled data from the 10-item Likert-type questions explained two key dimensions, which accounted for around 82% of the variation in the data. The two key dimensions were described as 'concern' and 'awareness'. The component 'concern' consisted of biomass resource depletion that denoted sustainability and environmental dimensions of bioenergy (Item nos. 1 and 2 respectively in Table 3, Article IV). This component indicated that the existing consumption pattern of biomass fuel does not match the rate of its growth, and would eventually lead to unsustainable utilization of resources. The component ‘awareness’ consisted of two aspects, i.e. the role of governmental agencies and local leaders, and future biomass fuel supply (Item nos. 6 and 7 respectively of Table 3, Article IV), which may be a strong influence on societies in regard to the development of mitigation strategies for biomass fuel demand. The items of this component did not only identify societal obstacles for the development of future biomass fuel supply but also suggested strategies and some options (e.g. introduction of short rotation forestry and growing of alternative biomass fuels as substitutes for wood fuels) to meet the demand for biomass fuel. However, both the ‘concern’ and ‘awareness’ components showed a satisfactory level of internal consistencies, as values were 0.91 and 0.59 respectively (Table 4, Article IV).

4 DISCUSSION

4.1 Evaluation the relevance of this study

Bangladesh is facing a severe energy crisis, particularly in the supply of modern forms of energy against a background of high energy demand. The country has limited fossil energy resources for power generation. As a result, power cuts, load shading and service interruptions frequently take place. More than one-third of the country’s population lacks access to a modern energy supply. The situation is even worse in the rural areas where the majority of the country’s population reside. More than half of rural households lack access to grid electricity, and nearly all do not have a gas supply (Asaduzzaman et al. 2010; Rahman et al. 2013). In addition, the negative impacts of climate change have placed additional threats on the livelihood of the rural populace of the country.

However, the country is endowed with vast renewable energy resources, such as biomass and solar. Promotion of these renewable energy resources could be an appropriate option for meeting the rural energy requirements, rural poverty alleviation, diversification of energy resources, and reduction of dependency on fossil fuel imports. The vast portion of rural household energy demand is met from biomass. Therefore, prospective planning and a comprehensive understanding of bioenergy dynamics are needed in order to achieve economic and social sustainability (Islam et al. 2008; Ullah et al. 2012). In fact, information on the socio-economic aspects of renewable energy sources, especially bioenergy supply and demand aspects are limited. The available data are mostly scattered and not well quantified. Hence, studies on bioenergy resource assessment, contemporary scenario analysis together with other socio-economic aspects are relevant for the formulation of sustainable rural energy strategies. Several studies have also emphasized the need to study rural energy dynamics in Bangladesh (Asaduzzaman et al. 2010; Ullah et al. 2012; Bahauddin and Salahuddin 2012; Hasan et al. 2013).

4.2 Evaluation of approaches for the assessment of bioenergy potential (Article I)

This study attempted to assess the bioenergy potential from selected agricultural crop residues and wood fuels in Bangladesh, and to predict resource potentials up to 2020. In general, two approaches can be undertaken to assess biomass resources: 1) demand-driven assessments that analyze the competitiveness of biomass-based electricity and biofuels, or estimate the amount of biomass required to meet exogenous targets on climate-neutral energy supply and 2) resource-focused assessments on the bioenergy resource base and the competition between different uses of the resources (Berndes et al. 2003). This study considered the second approach for the assessment of bioenergy potential, an approach also adopted by other studies (Fischer and Schrattenholzer 2001; Hoogwijk et al. 2003; Jölli and Giljum 2005; Hall et al. 2009; Mondal and Denich 2010). In this study, annual production data of selected agricultural crops and wood fuels were taken into account for the assessment. The existing database of Bangladesh Bureau of Statistics and FAO were explored for the collection of annual production data of selected agricultural crops and wood fuels, respectively. Since Bangladesh is heterogeneous in terms of crops and other biomass, the study therefore focused mainly on selected crops and wood fuels for the estimation of bioenergy potential.

In general, bioenergy potential is classified into three main types, namely theoretical, available, and economic potential (Voivontas et al. 1998). In addition, other types of bioenergy potential, such as technical, economical-ecological and ecological potential have also been categorized in some studies (Smeets and Faaij 2007; Milbrandt and Uriarte 2012). However, this study focused on available potential, defined as a part of the theoretical potential. The advantage of the available potential is that it maintains a number of environmental restrictions, i.e. minimum impact, legal constraints, safety reasons, accessibility etc., which promote sustainable harvesting practices. Crop residues can be categorized into field and process residues (Mondal and Denich 2010). Field residues are generally left in the field after harvesting and are typically used as a soil fertilizer. Process residues are generated during crop processing (e.g. while extracting grain from crops) and they are available at different locations (e.g. home yards, mill sites during processing). In this study, only process residues were considered for energy estimations. Moreover, some other types of biomass, such as animal dung, bamboos, leaf biomass, fronds of coconut, palm, and date tress as well as residues of other minor crops that are frequently used as biomass fuel by rural dwellers, especially for cooking were excluded from the study. Moreover, the bioenergy potential from waste resources was not considered in this estimation since the utilization of waste for energy-use is not found in rural areas of Bangladesh. Hence, the estimated bioenergy potential in this study represents somewhat less than the actual available bioenergy potential in the country.

The study applied different coefficients (crop-residue ratio) for quantifying residues from selected crops, which have also been applied in other studies in Bangladesh (Hossain and Badr 2007; Mondal and Denich 2010; Das and Hoque 2014). Furthermore, the study justified the reduction coefficients (non-energy and energy use ratio) of utilization of crop residues for non-energy purposes through a literature review coupled with cross-checks in the field. In addition, the study considered the energy content of biomass at the LHV level. The advantages of using LHV for bioenergy estimation is that it excludes latent heat that is released during the condensation of water produced in combustion, thereby representing net energy content through the complete combustion of biomass (Protásio et al. 2013). Residual coefficients, reduction coefficients, and the energy content of different biomass vary for several reasons, such as crop type, tree species, productivity, biomass density, moisture content etc. Changes to any of these factors may affect the estimation of the net amount of bioenergy potential. However, these approaches applied in this study were found to be useful and have also been applied in other studies (Koopmans and Koppejan 1997; Jölli and

Giljum 2005). Moreover, the production of crop and tree biomass also involves a number of uncertainties, such as the willingness and unwillingness of crop production, and land utilization for tree and other biomass production as well as the impacts of land-use changes and forestry, population growth and natural calamities, which were not taken into account in this assessment. Despite these limitations, the bioenergy potential in this study was estimated in a coherent manner.

This empirical study showed that the bioenergy potential of rice was rather high, and had increased significantly since 1990 as a result of increasing production. However, the estimated potential was somewhat lower than the findings of Zaman (2006) but higher than the findings of Mondal and Denich (2010). This was due to the application of different reduction coefficients used to estimate the bioenergy potential of the rice crop. The bioenergy potential from most non-rice crops has decreased considerably since 1990 due to a decrease in production. The study found that the amount of residues from non-rice crops were low, although this amount can be maximized as a higher portion of them remain unused (ca. 80%). In addition, the study revealed that bioenergy potential from tree resources has steadily decreased over time and the trend is likely to remain unchanged unless adequate interventions are implemented. Nevertheless, the approach applied in this study for the estimation of bioenergy potential is supported by several studies (Koopmans and Koppejan 1997; FAO 2000; Jölli and Giljum 2005).

The study used a ‘status quo’ benchmark and three alternative scenarios (scenario 1, 2, and 3) to predict the bioenergy potential up to 2020. The projection of the benchmark was based on the average growth rate of selected crops and wood fuels during the period 1990-2009, whereas the alternative scenarios were based on national GDP growth and expected GDP growth by 2015 under UN and GoB’s MDGs. The application of GDP for the projection of energy potential is rational since there is a causal relationship between economic growth and energy consumption (Chen et al. 2007). Among the alternative scenarios, scenario 2 was assumed to be the most realistic due to the modest growth rate. Since the 2000s, the annual growth in the forestry sector was 2% although it grew at 4% annually during the 1990s (FAO 2000; IMF 2005). Higher GPD growth during the 1990s was associated with the high exploitation of the forest resources in the country and resulted in a high level of deforestation and forest degradation. In contrast, scenarios 1 and 3 represented a higher potential due to high sectoral GDP growth rates resulting from the expected continuation of strategic policy frameworks on implementations, and technological developments. Nonetheless, there are some thresholds, i.e. land-use changes, cropping patterns, farmers’ attitudes, and policy instruments/programmes achievements, which are interrelated within each scenario. Therefore, the estimation in this study may not be accurate but rather illustrates an approximation of the production trend.

4.3 Evaluation on the perspectives of household energy consumption (Article II)

The methodologies applied in this study for the determination of rural households’ energy consumption patterns were found to be useful and supported by several studies (Howes 1985; Rao and Reddy 2007; Akther et al. 2010; Miah et al. 2010). The survey was carried out using a structured questionnaire that enabled the respondents to understand the intention of the survey clearly. Since interviews with the respondents was based on memory recall and estimates, the information concerning energy usage, expenditure and other relevant information may not be exact; rather it provided an approximation that was subsequently validated by spot measurements in the field. However, large-scale spot measurement is a challenge in terms of labor and cost. Taking these limitations into account, the study performed spot measurements on about 10% of the samples. The importance of spot measurements in the determination of household energy use has been recognized by earlier studies (Morgan 1980; Bhatia and Sharma 1990; Bari et al. 1998).

In general, rural households used biomass fuels and LPG for cooking while they used kerosene, candles, electricity and solar PV for lighting. The selection of fuel types and consumption patterns varied considerably with socio-economic status of the household. All rural households used biomass fuels and kerosene, and about half of them had access to grid electricity, while a smaller number used candles and LPG. Similar types of fuel consumption patterns were observed in rural Bangladesh by previous studies (Asaduzzaman et al. 2010; Miah et al. 2010). This study estimated that the monthly average household biomass fuel consumption was 2.95 GJ (819.4 kWh), which is close to the findings of the earlier study by Asaduzzaman and Latif (2005). The monthly average household consumption of non-biomass fuels was only 0.16 GJ (44.4 kWh) and consisted of electricity, kerosene and candles, which amounted to 30 kWh, 2.4 l, and 0.04 kg, respectively. Similar types of non-biomass fuels were also observed by Miah et al. (2010). This study revealed that the consumption of different non-biomass fuels by rural households was low and varied considerably between regions and socio-economic groups.

This study found that annual per capita primary energy consumption among rural households was low at 6.45 GJ. Earlier studies showed that annual per capita primary energy consumption among rural households of Bangladesh varied between 4.46 and 8.81 GJ (Alam et al. 1988; Douglas 1981). A more recent study has suggested that household energy consumption has increased by 2.5% annually during the last 25-30 years (Asaduzzaman et al. 2010). Thus, the findings of this study are in agreement with the previous studies in regard to the estimation per capita energy consumption of rural households. Nevertheless, this study found a significant positive relationship between household income and energy expenditure, which indicated that households with higher incomes were likely to spend more money for better energy fuels, such as firewood, LPG, and electricity. A similar type of attitude towards energy expenditure has been reported by other studies (Bhatt and Sachan 2004; Rao and Reddy 2007; Akther et al. 2010). One of the important findings of this study was that there was a reciprocal relationship between family size and energy household energy consumption. For instance, the consumption of total primary energy was seen to increase with a concomitant increase in family size, while in contrast per capita energy consumption decreased. Previous studies have also observed similar types of energy consumption patterns among rural households in the northern part of Bangladesh (Sarkar and Islam 1998; Bari et al. 1998). Nevertheless, societies are becoming elegance with the advancement of economy and technology; the income-based energy fuel choice may switch to modern and more efficient fuels. Therefore, policy interventions need to be accorded with the society's aspirations.

4.4 Evaluation of households' preferences, attitudes, knowledge and perception towards biomass fuels (Article III and Article IV)

Questionnaire survey-based methodologies were adopted in order to determine households' preferences, attitudes, knowledge and perception towards biomass fuels. The approaches were found to be effective and have also been applied in similar types of studies in Bangladesh (Miah et al. 2003; Jashimuddin et al. 2006; Miah et al. 2010), India (Badola 1998), China (Qu et al. 2012), and Jordan (Zyadin et al. 2012). The study revealed that firewood was extensively used as a cooking fuel in rural areas and was ranked the most preferred biomass fuel among the rural households. Due to limited resources and inequitable resource ownership, however, the use and selection of firewood as a cooking fuel varied among rural households. It was quite evident from this study that rich households preferred to replace inferior types of biomass fuels, i.e. crop residues with firewood, whereas middle-class households chose a mixture of both types, and poor households selected inferior types of biomass fuels. Similar patterns of firewood use and selection were reported among different socio-economic groups in many parts of rural Bangladesh (Miah et al. 2003; Jashimuddin et al. 2006; Akther et al. 2010) and in India (Mahapatra and Mitchell 1999; Pachauri 2004).

Several studies have demonstrated that energy fuel selection by households often depends on the energy ladder model (Heltberg 2003; Sclag and Zuzarte 2008). The model explains that households usually do not switch to a new fuel unless their income increases, although they may continue to use more than one fuel. This implies that when there is an increase in household income, a wide variety of energy fuels can now be afforded without leading to a decrease in the consumption of firewood. A likely similar trend was also observed in this study. Notwithstanding, some non-economic factors also influence biomass and other energy fuel selection. Such factors include the socio-economic status of rural households, education, the price of substitute fuels, availability or unavailability of fuel sources, distance to fuel sources, and accessibility to electricity and fuels (Alem et al. 2013; Osiolo 2009; Jan et al. 2012), which have also been espoused by this study.

Although firewood was found to be the most preferred biomass fuel among the rural populace, non-sustainable consumption affects both forest and agricultural systems. In rural areas of Bangladesh, trees on homestead and government lands are the main sources of firewood. This study has recognized that firewood consumption from both sources has been subject to overexploitation and has led to an acute shortage of firewood and a mounting cooking energy crisis in rural households. Since the early 1980s, the government has implemented a number of on-farm and off-farm afforestation programmes as it recognized the importance of tree planting programmes in rural areas of Bangladesh and to mitigate the cooking fuel demands (MoEF 1992). However, this study has found that most of the rural households were not sufficiently proactive towards tree planting on their farm lands, with the exception of some households who planted valuable timber tree species, such as *Swietenia mahagoni* and *Tectona grandis*. Such attitudes indicate that farmers are more focused on crop production than on future firewood supply. The study also found that rural households were more supportive of off-farm tree planting. This could infer that rural farmers are more interested in using their land for crop production rather than tree plantation. Therefore, policy makers need to emphasize the promotion of afforestation programmes on off-farm lands in rural areas, especially wood energy plantations on governmental lands. The promotion of wood energy plantations in rural areas has also been practiced in many Asian countries, such as China, India, Indonesia, Myanmar, Nepal, Pakistan and the Philippines (Mead 2001).

The study recognized that there currently is a wide gap between demand and supply of firewood in the study areas. Therefore, people have opted to use crop residues, cow dung and other inferior types of biomass for cooking fuels in order to cope with the firewood crisis. However, inefficient use of crop residues as fuel also results in a loss of organic fertilizers for agricultural lands, eventually threatening agricultural production systems. Similar phenomena on scarcity of firewood supply and the negative impacts of using inferior biomass as fuels has been observed by other studies (Asaduzzaman et al. 2010;

Miah et al. 2010). This study envisages that the development of wood-based resources and the acceptance of improved bioenergy and other renewable technologies could provide an efficient and clean energy supply to the rural populace of Bangladesh. However, several studies have suggested that the adoption of new renewable energy technologies depends on consumers' knowledge, perception and other socio-economic factors (Ekins 2004; Upham and Shackley 2006; Reddy and Balachandra 2006); and in the context of rural Bangladesh such factors are distinctly important for the promotion of any renewable energy technology. This study revealed that households' knowledge of biomass fuels was relatively high, for solar it was medium, and for wind and hydro power it was quite low. Earlier studies (Islam and Islam 2005; Kabir et al. 2010, Islam et al. 2011) validate the findings of the present study. Variations in knowledge of the different renewables among user-groups were also recognized in rural India (Khambalkar et al. 2010; Hasalkar et al. 2012), China (Qu et al. 2012) and Jordan (Zyadin et al. 2012). Furthermore, this study revealed that rural households were more knowledgeable on traditional biomass fuels, such as wood fuel, cow dung and crop residues, but possessed a limited knowledge on improved biomass fuels, such as briquettes, biogas, and biodiesel. The high level of knowledge of traditional biomass fuels perhaps resulted from the widespread use of these fuels for their daily energy use. About half of the rural households demonstrated a medium level of knowledge of briquettes, although economic inability restricted them from using this fuel. Furthermore, the lack of a sufficient number of biogas demonstration plants and the absence of biodiesel plants were recognized as the main constraints in the promotion of knowledge of these biofuels among rural households.

It was promising that a number of households adopted various renewable energy technologies, such as the installation of PV panels and biogas plants for their domestic energy use, which would indicate that the acceptance of renewable energy technologies is gaining traction among rural households. From 2003 to the end of 2012, more than 1.9 million solar home systems (SHSs) were installed by Infrastructure Development Company Limited (IDCOL), a government affiliated agency (Hamid 2013). In addition, approximately 25000 cow dung and poultry dropping based biogas plants have been installed throughout the country and another 37700 are under construction (Ullah et al. 2012; Bahauddin and Salahuddin 2012). However, the lack of exploitable feedstock (due to the small size of the cattle sector and the fragmentation of farming systems), and the lack of financial and technical incentives were identified as the main challenges to the popularization of biogas plants in the rural areas. The study found that most of the rural households used traditional stoves (which are often inefficient) and only a small portion of households adopted improved stoves for their household cooking activities. A lack of motivation, inappropriate stove models and unwillingness of consumers to change stove types (mainly due to high installation costs that are often unaffordable to poor households) were recognized as the main bottlenecks to the widespread application of improved stoves in the study areas. Similar types of obstacles to the promotion of improved stoves among rural households were also reported in many parts of Bangladesh (World Bank 2010), India (Hasalkar et al. 2012) and sub-Saharan Africa (Schlag and Zuzarte 2008).

This study identified that the lack of environmental awareness and lack of technical information were the main impediments to sustainable biomass fuel usage among rural households. In this regard, there are two noteworthy aspects to forestry and energy related policies: 1) future wood fuel supplies may become more unsustainable due to insufficient afforestation programmes; and 2) under-utilized government lands may be available, which could be managed as wood energy plantations. In these contexts, local leaders and relevant governmental departments could play leading roles in the utilization of set-aside lands for wood energy plantations. The study considered that the introduction of SRF in rural areas could help in the promotion of a sustainable wood fuel supply. Extensive afforestation programmes with fast growing SRF species, such as *Samanea saman, Albizia procera, Leucaena leucocephala, Acacia auriculiformis, Acacia nilotica, Acacia mangium, Dalbergia sissoo, Melia azedarach* and *Eucalyptus* spp. could be the right option to provide a sustainable firewood supply to rural households in Bangladesh.

Furthermore, the study highlighted two key components related to wood fuel supply dynamics: the wood-based bioenergy resources depletion trend, and the lack of societal awareness on future wood-based biomass fuel supplies. Therefore, adequate measures are essential to curb the ongoing degradation of existing wood-based resources and for building public awareness on the sustainable consumption of wood fuel. An intensification of the management of existing forest resources, enhancement of afforestation programmes on both private and government lands by the planting of appropriate SRF species, coupled with governmental priorities on the implementation of forestry sectoral plans and programmes are considered important interventions, which could bridge the gap between supply and demand of wood fuels and, eventually, promote future sustainable wood fuel supplies to rural households (MoEF 1992; Miah et al. 2010). In addition, the introduction of bioenergy related course curriculum at different institutional levels, the introduction of an adult learning programme on the environment, and the dissemination of information and technology on bioenergy through the mass media could be worthwhile interventions in the promotion of public knowledge, awareness and perceptions of bioenergy and other renewables (Islam and Islam 2005; Raza et al. 2011). However, in regard to current energy dynamics (i.e. supply and demand), the study recommended that a review of existing forest-energy related policies and the formulation of a 'biomass-based rural energy strategies/action plan' at national and/or regional levels are critically important interventions for energy security and sustainability bioenergy development in Bangladesh. Such policy frameworks could not only contribute to the provision of a sustainable energy supply but also could contribute to climate change mitigation and the promotion of living standards of the rural households.

5 CONCLUSIONS

The study provided perspectives of supply and demand of biomass based energy in rural Bangladesh. In the current context, the available bioenergy potential of selected crop residues and wood fuels was immense and varied substantially across all crop types (Article I). The residues from rice crops (i.e. rice straw and rice husk) were identified as the most promising source of bioenergy in Bangladesh. Wood fuels constituted the main biomass fuel at current consumption levels, but may decline in the future unless adequate interventions are put in place. The scenario analysis showed that the bioenergy potential from all selected crops could rise in combination with high sectoral GDP growth (as predicted by the country's MDGs, see scenario 4), whereas the bioenergy potential from wood fuels could be enormous if the trend of national sectoral (forest sub-sector) GDP growth continues into the future (scenario 1). This study implied that the forest resources of the country were subjected to intensive exploitation that eventually led to the deterioration and degradation of the wood-based biomass resources. Nevertheless, the study showed that wood fuels, crop residues, and cow dung are the main biomass fuels in rural areas; and that the share of these biomass fuels is over 90% of total primary energy consumption (Article II). However, the high consumption of biomass fuels from limited land resources is not matched by the growth rates of the fuels and has put an enormous strain on existing resources.

Firewood was found to be the most preferred and commonly used biomass fuel among rural households (Article III). However, the current trend of firewood consumption is not sustainable as there is a wide gap between supply and demand of firewood in rural areas. Therefore, due to a limited supply of firewood, rural households have opted for inferior types of biomass, which are often inefficient and cause indoor pollution, health problems, and loss of soil organic fertilizer. Although rural households were observed to possess a high level of knowledge of traditional biomass fuels, they had a relatively low level of knowledge on improved biomass fuels (Article IV). This means that there is a need for the widespread dissemination of information related to bioenergy and other renewable energy technologies. The depletion of tree resources both from homestead and forest lands, inadequate afforestation programmes, the lack of initiatives for the utilization of set-aside lands especially for wood energy plantation, the lack of societal awareness on future wood fuel supplies, the absence of technological inputs and incentives on renewables, and the lack of appropriate guidance and policy frameworks were identified as the main obstacles to biomass-based energy development in the study areas.

The study highlighted a number of limitations, such as the absence of appropriate production data, inconsistency in the existing data and limited sampling sites. The methodologies applied in the present study may not be sufficient to analyze accurate scenarios on bioenergy. However, they are highly useful in order to understand the realities of biomass based energy perspectives in the rural areas of the country. Households' preferences, attitudes, knowledge, and perceptions assessed through the questionnaire surveys were based on 'individual opinions' and/or "guesstimates" of the respondents, which may have involved a certain level of internal bias to address a particular concern of the respondent. Thus, further research is endorsed. However, the results and assumptions made in this study will aid in the prediction of supply forecast possibilities and the formulation of policy frameworks on bioenergy and other renewable energy dynamics from an end-user prospective. The study may also be useful in the development of microplans for the forestry and energy sectors at local, regional and national levels in Bangladesh and in other developing countries.

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APPENDIX

AI. Questionnaire used for survey on rural household energy consumption patterns (Article 2)

Date: Time:

District: Upazilla: Union: Village:

1. Respondent's Name: Age: Sex: M / F
2. Number of family members: (i) Under 15Years: (ii) Adult (iii) Total:
3. Education Level: □ Illiterate □ Primary □ Secondary □ Higher-secondary □University degree
4. Profession: □ Service □ Labor □ Agricultural worker □ Business □ Student □ Unemployment □ Housewife □ Others
5. Land (in decimal) (i) Homestead area: (ii) Agriculture land: (iii) Total land:
6. Type of housing (√):□Kacha (hut) □ Semi-Pucca (Semi-building) □ Building/Brick with metal roof
7. Household monthly income: Taka…………………………………………………….........
8. Source of income (√): □ Service □ Labor □ Agriculture □ Business □ Other (specify)….
9. Employment type (√): □ Permanent □ Temporary □ Seasonal □ Causal/Occasional
10. Please rank your most expenditure (Rank 1 to 5, where 1 denotes most and 5 denotes least): □ Food □ Energy/electricity supply □ Education □ Health/medicine □ Other (specify.
11. Could you inform what types of energy fuels you use (√): □ Biomass □ Electricity □ Kerosene □ Candle □ LPG □ Coal □ Gasoline generator □ Others (specify)……………….
12. Could you inform the sources of different energy fuels that you use for household purposes (√)

Fuel type	Home garden	Agri land	Neighbo-rer land	Khas/Fa-llow land	Forest/ plantation	Market	**PDB /REB
Biomass							
Electricity							
Kerosene							
Candle							
LPG							
Generator							
*Others							

*Others indicated combustible materials such as paper, garbage, plastic etc: **PDB (Power Development Board)/REB (Rural Electrification Board)

13. Could you inform the amount of monthly consumption of different energy fuels and their expenditure?

Types of energy used	Monthly consumption	Estimated expenditure (in Taka)
Biomass (kg)		
Electricity (kW/h)		
Kerosene (liter)		
Candle (kg)		
LPG (kg)		
Generator (kW/h)		
*Others (kg)		

*Others indicated combustible materials such as paper, garbage, plastic etc

14. Could you inform the sources of different biomass fuels that you use for household purposes (√)

Type of biomass	Home garden	Agri.land	Neighbo-rer land	Khas/Fa-llowland	Forest/ plantation	Market	Other
Stem wood							
Branch wood							
Leaves & twigs							
Bamboo							
Rice husk							
Rice straw							
Jute straw							
Agri. residues							
Cow dung							
Sawdust& slabs							
Other (specify)							

15. Could you inform the amount of monthly consumption of different biomass fuels and their expenditure?

Type of biomass	Monthly consumption (kg)	Estimated expenditure (in Taka)
Stem wood		
Branch wood		
Leaves&twigs		
Bamboo		
Rice husk		
Rice straw		
Jute straw		
Agri. residues		
Cow dung		
Briquette		
Sawdust&slabs		
Other		

16. What are the main usages of biomass fuels for your household purposes (in %)?

Cooking	Rice parboiling	Water boiling	Gur (Jaggery) making	Others (specify)

17. How does the biomass fuel collection take place (√): □ Collection by wife □ Collection by husband □ Collection by family member □ Collected by labor □ Collection by others (specify)

18. Frequencies of collection (√): □ Daily □ Weekly □ Monthly □ Seasonal (3-4 months) □ Yearly

19. What is the distance generally covered during biomass fuel collection (both way) (√): □ 0-1 km □ 0-2 km □ 0-3 km □ 0-4 km □ 0-5 km □ More than 5 km

20. How much time you generally spent for a single time of biomass fuel collection (both way) (√): □ 1-2 hour □ 2-3 hours □ 3-4 hours □ 4-5 hours □ more than 5 hours

A II: Questionnaire used for survey on rural households' preferences and attitudes towards biomass fuels (Article 3)

Date: Time:

District: Upazilla: Union: Village:

1. Respondent's Name: Age: Sex: M / F

2. Total land holding (area in decimal):

3. Household monthly income:

4. Source of income (√): Service Labor Agriculture Business Other (specify)…...

5. Which type of biomass you use for household energy use (Multiple options)?
 Stem firewood Branch firewood Leaves & twigs Bamboo Rice husk Rice straw Jute Straw Agri. residues Cow dung Briquette Sawdust &slabs None

6. If you use any type of biomass for household energy use, please provide the reasons (Multiple options): Economic inability because biomass is easily available It is almost free of cost It is easy to use It is cheap than other fuels There is no other alternatives for fuel Other (specify)…………..

7. If you do not use any type of biomass for household energy purposes, please provide the reasons (Multiple options): Biomass fuel is not available Difficult to collect Biomass fuels create smoke Housing patterns do not allow biomass for energy use Other
(specify)………..

8. What type of biomass fuel you prefer to use for cooking (Multiple options)? (1 denotes most one 12 denotes the least one): Stem firewood Branch firewood Leaves & twigs Bamboo Rice husk Rice straw Jute Straw Agri. residues Cow dung Briquette Sawdust &slabs None of these biomass fuels

9. What types of biomass fuels are more available? (1 denote most one 12 denote least one): Stem firewood Branch firewood Leaves & twigs Bamboo Rice husk Rice straw Jute Straw Agri. residues Cow dung Briquette Sawdust &slabs None

10. Please provide most available tree species (about 10) that are used for firewood (Local name):1…………………..2……………………3………………………...4………………
5…………………..………6…………………...7……………………..………8………………
9…………………………10……………………………………………………………..

11. How does the firewood collection take place (√): Collection by wife Collection by husband Collection by family member Collected by labor Collection by others (specify)

12. What types of difficulties you face for collecting biomass fuels?
(a)……………………………………………………………………………………..
(b)……………………………………………………………………………………..
(c)……………………………………………………………………………………..

13. Do you pay for collecting biomass fuel? Yes No
(i). If Yes in question 13, then what do you think about the market price of biomass fuel (such as firewood) in comparison to other commercial fuels such as LPG, Kerosene etc? High Low Don't know
(ii). If No in question 13, then what's the reason? It's grow in my own land Can collect freely from neighbor land Other (specify)………………………………………………… ………………………………….

14. Have you planted any tree on your land in the recent years? Yes No Don't know
(i) If Yes in question 14, then please provide the following information

Type of tree	When planted				No.planted trees	Still alive
	This year	Last year	Within 3 years	Within 6 years		
Fruit trees						
Timber trees						
Trees for fuel						
Multipurpose trees						
Bamboos						

(ii) If Yes in question 14, would you like to plant tree again on your land? Yes No Don't know
(iii) If Yes in question 14, then which purpose you would like to plant trees? For fruit For animal food For firewood For timber For future investment Aesthetic purpose Other (specify)…………………………………………………………………………
(iv) If No in question 14, then what are the reason(s)? No available land Seedlings are not available in the market Difficult to collect seedlings Seedling cost is high Lack of knowledge about planting and post-planting maintenance Other (specify)……………………………………………………………………………………
15. Do you agree with the idea of planting trees on government land? Yes No Don't know
(i) If Yes in question 15, which are suitable land for planting trees? Marginal lands of road, highway, and railway track Canal bank and embankments Forest land Khas land Other area (specify)………………………………………………………………….
(ii) If Yes in question 15, who should take leading role in tree planting program? Forest Department Other Government Departments NGOs Landless local people with cooperation of Government Departments Local cooperatives Other area (specify)……………………………………………………………………………………
(iii) If your answer 'No' in question 15, then what are the reasons? ....
16. Do you expect to get any benefit from govt. plantation program? Yes No Don't know
(i) If Yes in question 16, then what type (s) of benefit you expect? Financial through participation in the plantation program, Better supply of wood and fuel Protection of land and properties from flood and storm Other (specify)…………………………………
(ii) If your answer 'No' in question 16, then what's the reason? ....
…………………………………………………………………………………………………...
17. Have you got any benefit from govt. plantations? Yes No Don't know
(i) If Yes in question 17, then what type (s) of benefit you got? Financial Job Training Other (specify)…………………………………………………………………………….
(ii) If No Yes in question 17, then what is the reason (s)? I am not involved in this program I do not know where to contact Lack of information Other (specify)…………………
18. Do you think that afforestation program is important in this area? Yes No Don't know

A III: Questionnaire used for survey on rural households' knowledge and perceptions towards bioenergy resource development (Article 4)

District: Upazilla: Union: Village:

1. Respondent's name: Age: Sex: M / F
2. Total land (area in decimal):
3. Household monthly income:
4. Source of income (√): □ Service □ Labor □ Agriculture □ Business □ Other (specify)….
5. Education Level: □ Illiterate □ Primary □ Secondary □ Higher secondary □University
6. Profession: □Service holder □Worker/labor □ Farmer □ Business □ Housewife □ Other
7. Could you inform your level of knowledge about the following renewable energy sources?

Type of RES	Level of knowledge		
	High	Medium	Low
Solar panel			
Wind mill			
Hydropower			
Biomass			

8. Could you provide your level of knowledge about the following types of biomass fuel?

Type of RES	Level of knowledge		
	High	Medium	Low
Wood fuels			
Wood pellet			
Agri-residues			
Cow Deng			
Briquette			
Biodiesel			

9. Do you use any renewable energy (√): □Yes □ No.

(i) If your answer is Yes in question 9, then what types of renewable you use for domestic purposes (√):□ Biomass □ Solar panel (PV) □ Biogas □Other (Please specify):

10. What types of fuel you use for your household cooking (√): □ Biomass □ Natural gas □ LPG □ Kerosene □ Electricity □ Biogas □Other (Solar stove) □ Don't know
11. What type (s) of fuel you use for household lighting (√):□ Kerosene □ Electricity □ Solar panel (PV) □ don't know
12. Do you use IPS/Battery/Generator/Other device for off-time electricity (√):□Yes □No.

(i) If Yes in question 12, then what is the source (s)?..

13. Are you familiar with upgraded biofuel such as rice-husk briquette? □ Yes, I see and use □ I see but never use □ No, I never see it
14. Would you like to use upgraded biofuels such as rice husk briquette for your household cooking and other purposes? □ Yes □ No □ Don't know
15. If you would like to use rice-husk briquette for your household purposes (Yes in question 14), then please provide the reason(s): □ Easy to handle □ Do not create much smoke □ Efficient than other biomass fuels □ Price is cheap than kerosene, LPG and other commercial fuel □ Other (specify)……………………………..
16. If you would not like to use rice-husk briquette for your household purposes (No in question 14), then please provide the reason(s): □ Rice-husk briquette is not available in the market □ Supply chain is uncertain □ Price of rice-husk briquette is higher than other biomass fuels □ Need special type of oven □ Other reason (specify)……………………..

17. Suppose there is upgraded biofuels (rice-husk briquette) available in the market and the supply chain is secured. Would you like to use that product at your household for cooking and other purposes? □ Yes □ No □ Don't know

18. Would you like to pay more to buy briquette than other biomass fuel such as wood (Average price of one mound briquette is Taka 160 and one mound wood is Taka 80)? □ Yes □ No □ Don't know

19. Suppose, you are invited to attend a training program on upgraded biofuels and/or efficient use of biomass fuel': Are you willing to travel for long distance (Upazilla/District headquarter) for taking this training? □ Yes □ No □ Don't know.

(i) If your answer No in Question 19, then what are the reasons?

(a)……………………………………………………………………………………………

(b)……………………………………………………………………………………………

(c)……………………………………………………………………………………………

20. Do you use improved oven (Chula) for household cooking? □ Yes □ No.

(i) If Yes in question 20, then who made installed it? □ Myself □ Govt. staff □ NGO workers □ Don't know

(ii) If your answer No in question 20, then what is the reason(s)? □ I am not aware □ Nobody inform me □ It needs money for installation □ I do not have contact with the agency □ Other (specify)…………………………………………………………………

21. Is afforestation program important in this area? □ Yes □ No □ Don't know

(i) If Yes in question 21, then how much important you consider? □Extremely important □ Very important □ Important □ Less important □ Not important

(ii) If your answer No in Question 21, then what's the reason(s)? …………………………

22. Please provide your opinion on the following statements:

Statements	SA	A	DKn	D	SD
All biomass fuel resources are decreasing over the time in this area					
Tree resources are decreasing over the time in this area					
Existing govt. afforestation program is inadequate against local demand					
There is still enough unused land where AF program can implement					
Govt. department &local leaders need to pay more attention towards AF					
Use of biomass for energy demand is environmentally friendly					
Short rotation forestry is needed for biomass fuel production					
Future biomass fuel supply in this area is really a matter of concern					
There is lack of awareness in the society about future biomass fuel supply					
Use of alternative/improved biomass fuel(briquette) is growing in the area					

N.B. SA=Strongly Agree, A=Agree, DKn=Don't know, D= Disagree, SD=Strongly Disagree