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GLOSSARY OF ACRONYMS

AES	Annual Economic Survey
AGE	Applied General Equilibrium
BEST	Biomass Energy Strategy
Btu	British Thermal Units
CGE	Computable General Equilibrium
CH_4	Methane
CO_2	Carbon Dioxide
COMESA	Common Market for Eastern and Southern Africa
COP 15	The 15^{th} Conference of Parties of the United Nations Framework Convention on Climate Change
DEA	Data Envelopment Analysis
EMA	Environment Management Act
ESCOM	Electricity Supply Corporation of Malawi
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
Mega	$M = 10^6$
GHG	Greenhouse Gas
GLS	Generalized Least Squares
GNP	Gross National Product
GoM	Government of Malawi
HSSW	Harberger, Scarf, Shoven and Whally
IEA	International Energy Annual of the US Department of Energy
IEP	Integrated Energy Policy
IFPRI	International Food Policy Research Institute
IHS	Integrated Household Survey
ISIC	International Standard Industrial Classification
Kg	Kilogram
KLE	Capital-Labour-Energy
LPG	Liquid Petroleum Gas
MAC	Marginal Abatements Cost

MACC	Marginal Abatement Cost Curve
MAREP	Malawi Rural Electrification Programme
MES	Morishima Elasticity of Substitution
MKW	Malawi Kwacha (Currency)
ML	Maximum Likelihood
MSG	Multisector Growth Model
N_2O	Nitrous Oxide
NEAP	National Environmental Action Plan
NEC	National Economic Council
NECO	National Electricity Council
NEP	National Environmental Policy
NFP	National Forest Policy
NOx	Nitrogen Oxides
NSO	National Statistical Office
PMS	Poverty Monitoring System
RBM	Reserve Bank of Malawi
RES	Allen Relative Elasticity of Substitution
SADC	Southern African Development Community
SAM	Social Accounting Matrix
UNFCCC	United Nations Framework Convention on Climate Change
VNRC	Village Natural Resources Committees

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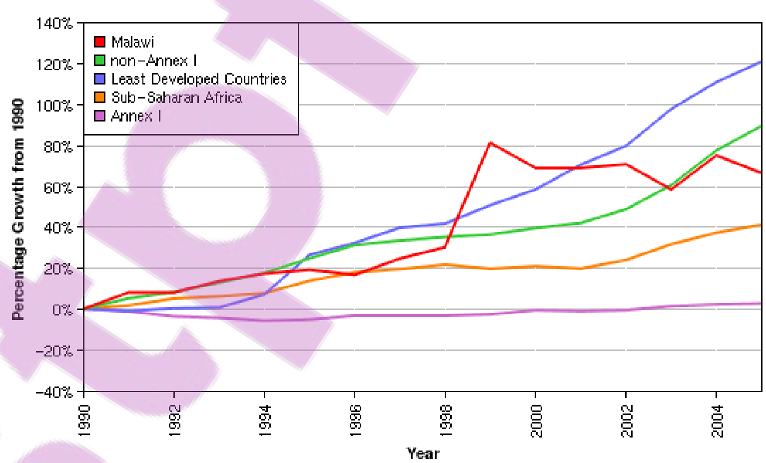
CHAPTER 1: INTRODUCTION AND MOTIVATION

There is international consensus on the need to reduce greenhouse gas (GHG) emissions from industrialized nations as evidenced by ratifications and continuing negotiations around the United Nations Framework Convention on Climate Change (UNFCCC). Specialised studies to estimate the cost of emission abatement have also been conducted in industrialized countries by among others Newell et al. (2006), Jaffe et al. (1999), Manne and Richels (1997), Jorgenson and Wilcoxen (1993), Nordaus (1991; 1993) and the Commonwealth of Australia (1991). However, not much is known about the viability of emission abatement strategies in developing countries of sub-Saharan Africa despite the fact that GHG emissions from developing countries have been rising faster than those from other countries and are projected to match those of industrialized countries by 2018 (Sathaye and Ravindranath, 1998). Moreover, cumulative emissions from least developed countries have been increasing at a faster rate than those from non-Annex I countries since 1990 (figure 1)[1].

Figure 1: National carbon dioxide emissions: 1990-2005



Source: World Resources Institute (2008), Climate Analysis Indicators Tool (CAIT, Version 6.0).

[1] The UNFCCC divides countries into three main groups according to differing commitments:(i) Annex I Parties include the industrialized countries that were members of the OECD (Organization for Economic Cooperation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States, (ii) Annex II Parties consist of the OECD members of Annex I, but not the EIT Parties; and (iii) Non-Annex I Parties are mostly developing countries, including 49 Parties classified as least developed countries (LDCs) by the United Nations (UNFCCC, 2008).

This study focuses on fuelwood and fossil fuel consumption by both producers and households as primary indicators of environmental pressure, while emissions of greenhouse gases are considered as by-products of these indicators. Although greenhouse gas (GHG) emission reductions are at this stage not obligatory for non-annex I countries under the UNFCCC, this study argues that developing countries such as Malawi could achieve better economic and environmental outcomes by implementing voluntary emission reduction strategies that address their local economic development problems. One of the economic problems is that developing countries use fuels less efficiently than industrialized countries because of lack of state-of-the-art technology. Fuel efficiency is also compromised because of the proportionately higher use of coal and biomass which produce more greenhouse gas emissions per unit of energy than do petroleum products and natural gas (Sathaye and Ravindranath, 1998).

Malawi is a typical least developed economy that is heavily dependent on natural resources for energy and livelihood. Economic growth has been accompanied by resource extractions and emissions that could compromise sustainable development of the country. However, there is a risk that current resource extractions have direct and cumulative impacts on ecosystem flows of energy and emissions that often disturb ecosystem equilibrium (Munasinghe, 1993; Adriaanse et al., 1997; Klauer, 2000; Kratena, 2004). For instance, the 1994 Malawi GHG inventory indicated that land use change and forestry contributed 96.3 percent of the Malawi's carbon dioxide (CO_2) emissions, and was a net emitter of 17, 512 Gg kg of CO_2. Agriculture also contributed 25.8 percent and 90.7 percent of methane (CH_4) and nitrous oxide (N_2O) emissions, respectively, while energy-related emissions accounted for 71.9 percent and 91.3 percent of CH_4 and nitrogen oxides (NOx), respectively[2]. It is estimated that currently Malawi emits 747,000 metric tons of carbon dioxide, representing a 25 percent increase in total emissions since 1990 (World Resources Institute, 2006). This however excludes emissions from land use change which for developing countries are a significant source of emissions.

Forest resource degradation in Malawi is attributed to unsustainable use of fuelwood to meet the economy's energy needs. Malawi's growing energy requirements have also resulted in

[2] The 1994 GHG Inventory for Malawi is the most recent available. This is contained in an initial communication to the UNFCCC by Malawi in 2002. This is acceptable since the Kyoto Protocol does not place reporting obligations on non-Annex I countries. However, reporting requirements might change especially after the new round of negotiations following Copenhagen in 2009. In particular, parties to the Kyoto protocol are expected to consolidate their commitments as early as December 2010 at the next round of negotiations in Montreal, Canada.

plummeting imports of oil over the years. Oil is the main source of energy for production activities, accounting for about two thirds of the total average annual energy expenditure by all production activities (NSO, 2001). In 2002, the daily import of refined petroleum products was 5,400 barrels of which 1,700 barrels was motor gasoline and 2,300 barrels distillate fuel oil (IEA, 2003). Demand for oil is so high that imports of petroleum products now exceed 8,000 barrels per day, and might reach 16,000 barrels per day by 2015 (IEA, 2008).

Between 2000 and 2006, the country's primary energy consumption per dollar GDP averaged 2021.1 British thermal units (Btu) per year, with energy intensity increasing at an average of 2.5 percent annually (IEA, 2008). Despite growing energy requirements, Malawi has been utilizing less than a quarter of its installed hydroelectric generation capacity (Livuza et al., 1997). Recent data shows that out of 1,453 GWh of electricity generated, only 30 percent is absorbed by domestic consumers while 1.2 percent is exported (UNESCO, 2008). Studies conducted in developing countries like China, Brazil, Mexico, India, Thailand and Vietnam generally conclude that abundance of domestic hydroelectricity is important for reducing CO_2/energy elasticities whereas scarcity of renewable energy sources is associated with non-declining CO_2/energy elasticities (Sathaye and Ravindranath, 1998). Malawi therefore has a clear opportunity for shifting the energy base of the economy from fuelwood and carbon-intensive fuels to hydroelectricity.

Although studies like Sathaye and Ravindranath (1998) offer an opportunity for energy and forestry management in developing countries, energy and technology interactions in the results could have been conditioned on erroneous assumptions of free market behaviour (Hyde et al., 1996). While hydropower is the most realistic alternative clean fuel in most developing countries, price effects associated with substitution elasticities among available fuels could be critical to reducing carbon emissions. According to Jaffe et al. (1999) inefficiencies in energy technology markets provide a unique opportunity for exploring inexpensive GHG mitigations through energy efficiency enhancement. However, there is little or no empirical evidence to support this suggestion for developing countries in sub-Saharan Africa region. The underlying question that this study therefore asks is whether Malawi could mitigate GHG emissions through energy efficiency without compromising output growth. In particular, the study seeks to understand the economic, environmental and policy factors that are necessary for successful implementation of GHG mitigation in developing countries.

1.1 Statement of the problem

The energy demand structure in Malawi has serious consequences not only for GHG emissions, but also for sustainable development. The economy's footprint in terms of fuelwood demand is putting tangible pressure on forest reserves and protected areas while rising GHG emissions from energy end users will seriously compromise future wellbeing of the nation.

Despite the gravity of problems caused by the complex interactions that environmental extractions and releases bring to bear on economic development, limited analyses have been carried out to quantify the overall environmental burden exerted by fuelwood demand for energy by economic activities and households. Economywide impacts of fuelwood and fossil fuel use by economic activities and households include forest resource degradation that lead to secondary environmental impacts such as soil erosion and watershed degradation (GoM, 1994a). Therefore, if deforestation and forest degradation continues without corrective measures, the result will be environmental hazards, erosion of biological diversity, deterioration of wildlife habitat and degradation of water quality and quantity (FAO, 2003).

It is imperative to study the effect of shifting the energy demand profile of households and industries from biomass base to more modern and less environmentally damaging energy sources like hydroelectricity and biogas. Previous sectoral analyses of environmental problems mainly focused on impacts of agriculture on soil erosion, forestry and watersheds (French, 1986; Hyde and Seve, 1993; Nankhumwa, 2004). Although adequate for sectoral policies, sectoral analyses often raise recommendations that cause problems of coordinating policies in a large number of different and often non-cooperating government ministries (Munasinghe, 1993). In addition, some sectoral policies may be inconsistent with social goals such as poverty alleviation. Economywide perspectives are critical because poverty and low access to electricity have been linked to over dependency on biomass energy and over-exploitation of forest resources in Malawi (GoM, 2002).

It is therefore crucial to link sectoral policy changes to economywide environmental and distributional outcomes in an integrated framework. A complete and accurate assessment of the human impact on the environment requires a greater understanding of linkages between the environment and economic processes, in addition to the extensive exchanges between different parts of the economy in the market system. Sustainable development will entail an extensive valuation of environmental resources and damages arising from conventional economic activities (Munasinghe, 1993). There is therefore a need to quantify the material throughput in the Malawi economy in terms of fuelwood and fossil fuel use and emissions linked to their use.

French (1986) projected solid wood demand deficits for Malawi under different policy options aimed at mitigating deforestation. The policy menu included planting new trees to replace the ones cut down, improving efficiency of fuel use and making alternative sources of energy competitive. The study painted a grim future for the energy sector in Malawi in that all suggested policies failed to cut the fuelwood deficit to sustainable levels. However, the study did not explicitly model producer and consumer incentives and how these influenced energy demand over time. Currently, household consumption of fuelwood and charcoal is estimated at 7.5 million tons per year which is 3.7 million tons above sustainable supply (Chagunda et al., 2009).

Among the policy initiatives aimed at changing the energy end-use profile for Malawi is the Malawi Rural Electrification Programme (MAREP). MAREP was launched in 1980 with the aim of increasing the number of people with access to electricity to 10 percent of the population by 2010 (GoM, 2001c). Although the fifth and final phase began in 2003 with a study and development of a Rural Electrification Master Plan, there is no independent empirical study to show the economywide impact of rural electrification on households' and producer energy choices and on the rate of deforestation. In a study of rural households in Bushbuckridge in South Africa, Madubansi and Shackleton (2007) argued for the need to determine changes in biomass consumption rates and harvesting rates before and after introduction of electricity in a longitudinal survey of same households. Like French (1986), Madubansi and Shackleton (2007) did not delineate behavioural factors determining the high proportion of households still using fuelwood 10 years after the introduction of subsidized electricity.

An equally important issue is energy-related greenhouse gas emissions. Carbon dioxide (CO_2) emission from gaseous fuels, cement manufacturing and solid fuels was estimated at 747,000 tons in 1998, representing a 25 percent increase in emissions from 1990 (GoM, 2002). Although GHG emissions reductions are at this stage not obligatory, Malawi could take advantage of the opportunity to reduce emissions to correct distortions in its domestic energy markets. It is the argument of this study that fuel expenditures by poor households may be reduced by a deliberate policy that supports less environmentally damaging fuels like hydroelectricity and biogas. In addition, reducing energy-related GHG emissions now may be equivalent to averting long-term impacts on the environment (Biesiot and Noorman, 1999). A policy that supports alternatives to biomass and fossil fuels may also benefit the environment by arresting the rampant deforestation that is threatening natural forests in Malawi. However, for such a policy to be relevant there is need to identify factors that determine household and industrial fuel choices apart from the regular price considerations in energy demand analysis.

This study is unique in that it suggests solutions to greenhouse gas emissions within the economic development agenda for Malawi. Literature search reveals that this is the first study in Malawi to analyse the economywide impacts of shifting the energy mix from biomass base to modern fuel sources. This has policy relevance in that the proposed GHG emission reductions are voluntary and yet such emission reduction strategies have the potential to arrest deforestation and improve efficiency of the hydroelectric energy sector. The study will also contribute to the literature on the prospects of a double dividend from implementing voluntary GHG emission mitigation policies in developing countries. In terms of methodological contribution, the study not only estimates energy substitution elasticities in an interfuel partial equilibrium model but also uses an economywide framework to directly estimate the optimal energy mix and implicitly, optimal emissions. This is an innovation in that emission reduction targets are endogenously determined by the model and not arbitrarily by the researcher.

1.2 Objectives

The main objective of this study is to evaluate the implications of voluntary reduction in energy-related emissions on the environment and on economic welfare in Malawi.

To achieve the above main objective, the study will pursue the following specific objectives:

1) Estimate interfuel substitution elasticities.
2) Analyse the partial equilibrium impacts of alternative fiscal policy regimes that taxes high carbon fuels and subsidizes alternative low carbon substitutes on energy and carbon intensities.

3) Estimate elasticity of substitution among fuels in the energy aggregate input and elasticity of substitution between energy and non-energy aggregate inputs.
4) Analyse short-run and long-run structural adjustment parameters of substitution in production.
5) Analyse economywide impacts of alternative fiscal policy regimes that taxes high carbon fuels and subsidizes alternative low carbon substitutes.
6) Analyse environmental gains/losses in an economywide framework of alternative fiscal policy regimes that taxes high carbon fuels and subsidizes alternative low carbon substitutes.
7) Determine the optimal fiscal policy regime and thereby the optimal energy mix for the country.

1.3 Hypotheses

The study hypothesizes that:

For industrial energy demand analyses:

1) All fuels in the energy aggregate are Morishima substitutes for each other.
2) Capital, labour and energy input aggregates are Morishima substitutes for each other.
3) The rate of long-run adjustment in intensity of energy use is faster in low capital economic activities and vice-versa.

For the economywide analyses:

1) The economic impact of a fiscal policy regimes that taxes high carbon fuels and subsidizes alternative low carbon substitutes would be negative for capital intensive sectors but positive for labour intensive sectors
2) The positive impact of fiscal policy regimes that tax carbon-intensive fuels and subsidizes alternative low carbon fuel substitutes on labour intensive sectors would be offsetting their negative impact on capital intensive sectors resulting in a positive overall net economic impact (gains).
3) Simultaneous environmental and welfare improvements (double dividend) are feasible from a fiscal policy regime that taxes high carbon fuels and subsidizes alternative low carbon substitutes.

1.4 Organization of the thesis

This thesis is organized in 7 chapters. Chapter 2 provides an overview of energy supply and use in Malawi. Chapter 3 is a theoretical background of the study and discusses the literature. Chapter 4 describes the study approach. Chapter 5 presents estimates of interfuel substitution and dynamic adjustments in input demand. The general equilibrium implications of voluntary reductions in energy-related are evaluated and discussed in chapter 6. Chapter 7 summarises findings and concludes the thesis with policy recommendations.

CHAPTER 2: ENERGY SUPPLY AND USE IN MALAWI

This chapter provides an overview of the energy supply and use in Malawi. The first section discusses the structure of the economy of Malawi. The second section discusses the aggregate energy supply and use and presents the energy balance for Malawi. The third and fourth sections discuss the composition of energy demand by production activities and by households. The fifth section discusses the impact of biomass energy use on forest resources and cover. The Malawi national environmental policy framework is discussed in section six. A conclusion section summarises the chapter.

2.1 Economic structure

The Malawi economy is driven by agriculture which contributes an average of 35.8 percent to GDP, and about 86 percent to export revenues annually. The agriculture sector has the highest employment with over 68.72 percent of the total labour force directly engaged in agriculture, fishery and forestry (NSO, 2000). For the last decade ending in 2004 the macroeconomy was characterised by an annual GDP growth rate of 4.15 percent. This was achieved mainly through growth in non-agricultural sectors such as mining, construction and financial and professional services. The only traditional sector where growth has been significant over the years is small-scale agriculture (RBM, 2006).

The agricultural sector is organized in a dual structure consisting of large-scale commercial estates with vast landholdings and small-scale farmers with small land ownerships. Typically, estates have legal and institutional rules regulating land tenure, crop production, and occasionally their marketing and pricing. There are about 30,000 estates occupying over 1.2 million hectares and about 2 million households operating as smallholder farmers on 6.5 million hectares of freehold land. Approximately 25 percent of smallholder farmers cultivate less than 0.5 ha on average, 55 percent cultivate less than 1.0 ha, 31 percent cultivate between 1.0 and 2.0 ha and 14 percent cultivate more than 2.0 ha (FAO, 2003).

Economic growth in the whole economy is largely influenced by changes in small-scale agriculture, the contribution of which to agricultural value added for the preceding decade averaged 77.5 percent. Smallholder farmers contribute about 80 percent of the national agricultural production, and about 20 percent of agricultural exports, while estates account for 20 percent of the agricultural production and 80 percent of the exports (FAO, 2003). Small-scale agriculture registered an average annual growth rate of 11.3 percent between 1995 and 2004. In contrast, large-scale agriculture registered an average annual growth of 4.5 percent while the entire agricultural sector grew by 9.4 percent annually[3].

Malawi exports comprise mainly agricultural products. The countries that import from Malawi by order of importance are South Africa (15%), United States of America (9%), Germany (9%), Netherlands (7%), and Japan (<5%). Tobacco account for an average of 59 percent of the country's exports while manufactured and other products together account for 19 percent (Table 1). The composition of exports has remained stable for the last decade and there is no real movement towards non-traditional exports. Mulaga and Weiss (1996) found that about a third of manufacturing activity is based on the processing of agricultural goods for export, while the majority of the remainder is production of light consumer and industrial goods. Currently non-agricultural manufactured exports account for about 12 percent of total merchandise exports while tobacco and beverages account for 56 percent of exports (UN COMTRADE, 2009).

Furthermore, the economy faces unfavourable shifts in the terms of trade with falling prices for the traditional exports like tobacco, tea and sugar (Mulaga and Weiss, 1996). Export prices declined by 44 percent between 1995 and 2002, with the exception of 1998 when export prices were higher than average. This is in contrast to rising unit prices of imports averaging 31.9 percent annually between 1995 and 2002. Consequently the value of imports rose by an annual average of 35.9 percent for the period 1994- 2002. Transport costs account for about 30 percent of the total import bill. Oil, intermediate manufacturers and transport equipment are major imports. The main import sources by order of importance are South Africa (38%), Zimbabwe (18%), Zambia (8%), and Japan (4%) (NSO, 2002).

Since independence in 1964, the economy's trade strategy was to develop manufacturing capacity driven by strong primary export capacity in tea, tobacco, and sugar (Mulaga and Weiss, 1996). However, the performance of manufacturing has not impressed much on the

[3] Calculations of sectoral contribution to GDP and growth rates are based on National Accounts data from the Reserve Bank of Malawi, www.rbm.mw.

economy in recent years. For instance, the contribution of all sub-sectors in manufacturing contributed less than 30 percent to GDP in 1998. During the preceding decade up to 2004, manufacturing was the third largest sector after agriculture and distribution services, contributing an average of 12.97 percent annually to GDP.

Table 1: Domestic exports shares by product category: 1998-2006

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	Annual Average
Total Exports (MKW million)	15770.3	18360.9	23370.0	29913.2	29406.6	39944.9	52300.1	59227.3	73374.3	37963.1
Agric. products	**88%**	**87%**	**86%**	**81%**	**83%**	**75%**	**78%**	**78%**	**75%**	**81%**
Tobacco	65%	66%	63%	61%	61%	50%	54%	56%	54%	59%
Tea	8%	9%	9%	9%	9%	9%	10%	10%	9%	9%
Sugar	10%	6%	10%	8%	12%	12%	8%	8%	9%	9%
Coffee	1%	1%	2%	1%	1%	1%	4%	3%	2%	2%
Cotton	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
Rice	2%	2%	1%	1%	1%	1%	0%	1%	0%	1%
Pulses	1%	2%	1%	0%	1%	1%	1%	1%	1%	1%
Maize	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Other products	**12%**	**13%**	**14%**	**19%**	**17%**	**25%**	**22%**	**22%**	**25%**	**19%**

Source: Balance of Payments Accounts from the National Statistical Office.

In 1998, the manufacturing sector contributed 31.6 percent to the domestic supply, compared with 17 percent services and 6.2 percent agriculture. However, the domestic sales of non-agricultural manufactured goods averaged 42 percent of total sales between 1999 and 2001 (NSO, 2003). The high dependence on agricultural processing is one of the reasons manufacturing has been weak. This exposes the manufacturing sector to the same risks that agriculture is facing. There is also a high import content in intermediate inputs used by the manufacturing sector. For instance, the share of imported inputs to manufacturing in 1998 was 65.7 percent compared with 26.5 percent to services and 7.8 percent to agriculture. This trend is contributing significantly to the growing import bill which has quadrupled in 6 years from MKW27,414 million in 2000 to MKW143, 406 million in 2006 (RBM, 2008).

The macroeconomic performance of the economy determines the microeconomic outcomes such as production efficiency and income distribution. In general, agro-based sectors are crucial in determining macroeconomic aggregates and microeconomic outcomes. Depending on which source one is quoting, poverty headcounts in Malawi varies from 54 to 65 percent of the national population, and between 66.5 and 89.7 percent of rural population (NEC, 2000;

World Bank, 2008; Chen et al., 2009)[4]. At district level, Ntcheu, Ntchisi, Zomba, Thyolo, Mwanza and Phalombe have poverty headcounts of over 75 percent (NSO, 2000). The poverty incidence and severity are a reflection of the sources and distribution of income in the economy. About 78 percent of the income accruing to rural households is from agriculture labour, 12 percent from land, 5 percent from enterprise and 4 percent government. Urban households on the other hand get most of their income from enterprises (i.e., 55% from capital ownership), followed by labour (33%), land (10%) and government (2%).

Since smallholder agriculture is the economy's growth engine, there are indications that the economy's growth will continue to put pressure on forest resources and cover as a result of biomass energy use and conversion of forests to agricultural land. It is also expected that as manufacturing expands, there would be an increase in fuelwood demand because of the large agro-processing component (especially of sugar, tea and other food products) in manufacturing. This might be followed by a surge in demand for electricity since manufacturing is also a leading user of hydroelectricity among production activities.

For households, biomass will remain the most important source of energy for the foreseeable future. Apart from the high incidence of poverty which typically means that most households cannot afford modern sources of energy, the other reason for the pervasive reliance on fuelwood is that it is available at no fee or restriction on most customary lands. In urban and semi-urban areas however, high tariff of electricity is a contributing factor, as many people cannot afford to use electric power, hence there is lack of appropriate alternatives technologies to substitute firewood and charcoal (FAO, 2003).

2.2 Aggregate energy supply and use in Malawi

The energy needs of the Malawi economy are almost entirely met from biomass sources. Biomass energy consists mainly of fuelwood and charcoal produced from open access forest resources within Malawi. Other biomass sources include fuelwood from private forests or from farms, public forests and from protected lands owned by government. It also includes crop residues, weeds and animal droppings (GoM, 1994a; UNESCO, 2008). Fuelwood and

[4] A re-evaluation of progress towards achieving millennium development goals (MDGs) by World Bank shows that poverty levels have declined. However, this progress depends heavily on a re-calibration of poverty lines from $1/day in MKW at 1993 purchasing power parity to $2/day, which is equivalent to cost of basic needs (World Bank, 2008). A more rigorous discussion of recalibration of poverty lines for Malawi is provided by Chen et al. (2009).

charcoal account for about 93 percent of total energy consumption by Malawian households (UNESCO, 2008; Chagunda et al., 2009). The agricultural sector and households are the main users of biomass fuel accounting for over 90 percent of their energy requirements. Other production activities mainly rely on hydroelectricity and fossil fuels (NSO, 2000; NSO, 2005).

Electricity Supply Corporation of Malawi (ESCOM) is the sole generator and distributor of hydro-energy with an installed capacity of 308.5 Megawatts. It has three power generating stations on Shire River in southern Malawi namely, Tedzani, Nkula and Kapichira that account for 98.5 percent of the installed capacity. Wovwe is the only other power generating plant further north on Rukulu River. At maximum use, household demand for electricity accounts for less than 2 percent of installed capacity whereas industrial demand accounts for 21 percent of capacity. An additional 1 percent is being exported to neighbouring Mozambique, implying that only a quarter of the installed capacity is being utilized (Livuza et al., 1997). Recent estimates put peak domestic demand at 31.2 percent of installed capacity, including 17.4GWh export to neighbouring countries (UNESCO, 2008).

Malawi does not produce energy balance data. However, the International Energy Annual (IEA) published by the United States Department of Energy has some energy production and use data that could be used to produce the energy balance for Malawi (Table 2). The IEA of 2003 shows that except for hydroelectricity, Malawi's energy requirements are met from imports. This excludes fuelwood from total energy supply as biomass sources are not captured in the IEA. As pointed out above, fuelwood and charcoal are the only sources of energy for most households in Malawi. The major energy import is oil consisting of mainly petroleum and diesel, except about 3 percent (18 million litres per annum) of the requirement which is met by locally produced ethanol (NSO, 2002). However, ethanol production is far short of the required 20:80 petrol-ethanol blend as the current annual production translates to 12:88 petrol-ethanol blends (NORAD, 2002).

Coal and natural gas are also imported, albeit in smaller quantities compared with oil. Currently, the country imports as much as 0.1 trillion Btu of primary coal and metallurgical coke to supplement annual production of 65,000 metric tons (IEA, 2008; Nationmaster, 2009). Coal production in 2007 represents only 59 percent of total annual demand of over 110,000 metric tons in 1992 (GoM, 1994a). For the last four years, expenditure on oil products averaged 998.5 million Kwacha per annum (7.8 percent of GDP) while expenditure on coal by industries averaged 54 million Kwacha per annum, representing 0.4 percent of GDP (NSO, 2002) [5].

Table 2: Production and consumption of some primary energy sources

	Consumption			Production
Year	Petroleum ('000 barrels per day)	Coal (Million short tons)	Electricity (Billion KWh)	Hydroelectric net installed capacity (MW)
1998	5.0	0.02	1.00	308.5
1999	5.0	0.02	0.96	308.5
2000	5.3	0.02	1.00	308.5
2001	5.3	0.02	1.02	308.5
2002	5.4	0.02	1.14	308.5
2003	5.5	0.02	1.15	308.5
2004	6.0	0.02**	1.27	308.5
2005	7.0	0.02**	1.37	308.5
2006	7.0	0.02**	1.10	308.5
2007	7.0	-	-	308.5
2008	8.0	-	-	308.5

Notes and sources: IEA (2003).*http://www.indexmundi.com ; **UNData Energy Statistics Database; - No data

The discussion that follows in section 2.3 is based on energy use and supply data extracted from the Annual Economic Survey (AES) conducted by the Malawi National Statistical Office. The AES is by design a panel of companies that reflects the current economic situation in the industrial sector, and does not necessarily focus on energy issues. The variables in AES include sale of goods, stocks, purchases of intermediate materials and supplies used in production, employment, capital investment in fixed assets, and profit.

2.3 Energy consumption by production sectors

Oil (diesel, petroleum and other lubricants) is the main source of energy for production sectors, accounting for about two thirds of the total average annual energy expenditure by all production activities (Table 3). Hydroelectricity is the second important source accounting for an average of a third of the total annual energy expenditure by all production activities between 1998 and 2001. Coal and fuelwood are major alternatives to hydroelectricity and oil. Natural gas is also an alternative source of energy in Malawi although its use and supply is still minor. Virtually all gas supplies are imported from South Africa (NSO, 2002).

[5] The annual average exchange rate (Kwacha per dollar) for the period was K56.70.

Table 3: Share (%) of total energy expenditure by industry and source between 1998 and 2001

Industry/Sector	Electricity	Fuelwood	Oil products (petrol, diesel and other lubricants)	Coal	Gas
percent of the total annual energy expenditure by all production activities	32.6	1.5	61.7	3.3	0.8
Manufacturing	60	48	28	100	100
Services	21	-	48		
Distribution	9	-	13		
Water and Electricity	5	-	4		
Agriculture	3	52	3		
Construction	1	-	2		
Mining	1	-	2		
Total	100	100	100	100	100

Source: AES (NSO, 2002).

There are important differences in sources and requirements of energy by production sectors. To a large extent, the nature of products produced and the technology employed determine the type of energy that would be appropriate for an activity. Electricity is mainly used by manufacturing and services (Table 3). Fuelwood is used by agriculture and manufacturing sectors only whereas oil products (petrol, diesel and other lubricants) are mainly used by the services sector. Among production activities, gas is used by four sub-sectors of the manufacturing industry only. Among these, fabricated metal production is the major user contributing 82 percent to total demand for gas. Ethanol is used by the activity of retailing auto fuel (distribution) for blending with petrol. Molasses, which is a by-product of sugar manufacturing, is also used by bakeries and confectioneries. However, the volume and value of molasses are negligible.

"Tobacco and sugar growing" dominate energy demand by all agricultural sub-sectors. The sub-sector is the main user of fuelwood and hydroelectricity in agriculture, and only second in ranking to "tea, coffee and macadamia growing" for its demand for oil products (Table 4). Tobacco farmers are the largest consumers of industrial wood, both for posts and for curing tobacco. It is estimated that estates alone use about 84,826 m^3 of firewood for curing tobacco per annum (GoM, 1998a). However, "tea, coffee and macadamia growing" and "tobacco growing" are almost at par in proportional terms for fuelwood demand within agriculture.

Table 4: Agricultural sub-sectors contribution (%) to total expenditure on various energy sources

Agriculture sub-sector	Fuelwood	Hydroelectricity	Oil products
Dairy farming	0.9	1.3	0.6
Fishing		2.6	11.4
Horticulture		0.9	2.1
Poultry farming		4.8	10.3
Tea, coffee and macadamia growing	5.0	42.3	52.2
Tobacco & sugar	94.1	48.1	23.5
Total	100	100	100

Source: AES (NSO, 2002).

Among distribution sub-sectors, "wholesale on a fee or contract basis and wholesale of agricultural raw materials" and "retail sale in non-specialised stores" are the main consumers of hydroelectricity. "Wholesale on a fee or contract basis and wholesale of agricultural raw materials" is also the main consumer of oil products among distribution sub-sectors. Ethanol on the other hand is only used by the activity of sale of automotive fuels (Table 5).

Table 5: Distribution sub-sectors contribution (%) to total expenditure on various energy sources

Distribution sub-sectors	Hydroelectricit y	Oil products	Ethano l
Retail sale of hardware, paints, and glass	2.4	3.5	0.0
Maintenance of motor vehicles	3.1	1.5	0.0
Other retail sale in non-specialised stores	8.2	17.9	0.0
Retail sale of automotive fuels	9.5	21.5	100.0
Retail sale in non-specialised stores, pharmaceutical and toilet articles	31.6	5.2	0.0
Sale of Motor vehicles	12.7	6.5	0.0
Wholesale on fee and of agricultural raw materials	32.6	43.8	0.0
Total	100.0	100.0	100.0

Source: AES (NSO, 2002).

The manufacturing sector's demand for energy from oil, hydroelectricity and fuelwood is consistently dominated by the production of "tea and other food products" (Table 6). The bulk of the demand for electricity by manufacturing is from the sub-sectors of "rubber tyres and plastic products" and the manufacturing of "tea and other food products". For oil products, the productions of soft drinks and of "tea and other food products" are the major users of oil. For coal, the productions of "soaps, detergents and toiletries", "malt liquor and malt" and of "soft drinks" are the main users. Gas is mainly used in the productions of "fabricated metal" and "batteries and motor vehicle trailers". Fuelwood on the other hand is mainly used in the production of "tea and other food products" and sugar.

Table 6: Manufacturing sub-sectors contribution (%) to total expenditure on various energy sources

Manufacturing sub-sector	Oil	Hydroelectricity	Fuelwood	Coal	Gas
Bakeries and confectionaries	3.9	1.0			
Batteries & motor vehicle trailers	0.4	0.3			11.4
Cement, lime & plaster	1.8	5.9			
Dairy products	2.4	2.1			
Distilling spirits	1.9	0.7			
Fabricated metal	1.1	0.9			84.9
Fertiliser & plastics	0.2	0.6			
Footwear (leather)	0.8	2.2			
Furniture & other wood products	5.4	4.0	2.4		
Grain milling	5.5	4.6			
Malt liquor and malt	8.8	4.5		22.8	
Tea and other food products	13.4	13.0	77.4		
Paper	2.3	1.4	1.0	3.3	
Meat production	0.7	0.6			
Paints Vanishes	2.4	0.6			
Pharmaceuticals	1.6	0.7			
Printing (books, magazines)	0.3	0.1			
Publishing books	0.1				
Publishing newspapers	1.8	0.5	1.8		2.7
Rubber tyres & plastic products	6.8	33.5			
Sawmilling & planning of wood	0.2	0.2			
Soaps, detergent	4.4	3.4	1.9	62.8	1.0
Soft drinks	19.3	6.4		11.1	
Stamping of metal	0.4	0.4			
Structural metals	6.9	2.0			
Sugar	1.9	4.6	15.4		
Textiles and wearing apparel	5.4	5.9			
Total	100.0	100.0	100.0	100.0	100.0

Source: AES (NSO, 2002).

For services, the sub-sector of "banking and other financial services" is the main user of hydroelectricity, while "Water and air transport" is the main consumer of oil products (Table 7). It is also apparent that sub-sectors of "Water and air transport" and "Freight transport" are also significant consumers of hydroelectricity and oil products, respectively. Passenger land transportation also consumes significant amount of electricity, followed closely by national postal services, insurance and real estates, and "restaurants, bars and hotels". For oil products, telecommunications, other businesses and passenger land transport are other significant users.

Table 7: Services sub-sectors contribution (%) to total expenditure on various energy sources

Services sub-sectors	Hydroelectricity	Oil products
Banking & other financial services	21.5	9.5
Cargo storage	5.2	1.5
Education	3.0	0.7
Freight transport	4.1	21.7
Human health activities	2.4	0.2
Insurance and real estates	8.5	4.5
National postal services	9.0	3.0
Other business	2.4	8.4
Passenger land transport	10.6	6.0
Personal and social services	5.0	0.9
Rail transport	6.2	2.6
Restaurants, bars and hotels	7.1	1.1
Telecommunication	2.8	8.7
Water & Air transport	12.0	31.1
Total	100.0	100.0

Source: AES (NSO, 2002).

2.4 Energy consumption by households

Household energy use data were extracted from the Integrated Household Surveys of 1998 and 2004 conducted by the National Statistical Office. The Integrated Household Surveys are nationally representative, and contain intercensal information on many household indicators. Other reports cited like NEC (2000) and PMS (2000) are based on these and other nationally representative household surveys.

For most Malawian households, access to efficient and modern sources of energy is still limited. Most households still rely on biomass fuels consisting mainly of fuelwood, charcoal and animal waste. Overall, 94 percent of households use fuelwood whereas only 2 percent use electricity as their main source of energy for cooking. In rural areas, up to 98 percent of households use fuelwood whereas less than 0.005 percent uses electricity as their main source of energy for cooking. In addition, only 5 percent of households in Malawi use electricity for lighting, and this include only 0.01 percent of rural households (NEC, 2000).

Markets have naturally responded to the shortage of fuelwood supply by adjusting the price of fuelwood upwards. For instance, between 1985 and 1995, fuelwood prices were increasing by an average of 5 percent annually. Hyde et al (1996) suggest that expenditure on fuelwood may have exceeded 20 percent of the cash income of some subsistence households in rural areas during the same period. According to PMS (2000), poor households in urban areas allocate up to 7.7 percent of their per capita daily expenditures to fuels that mainly consist of fuelwood and charcoal.

There are low scale initiatives to find alternative energy sources for households. This includes an underground biogas plant developed at Mzuzu University. The technology includes a biogas plant consisting of a digester with a feed capacity of manure from 4-6 cows to produce about 3m^3 of gas/day when working at 70 percent efficiency. The gas so produced is enough to operate 3 kitchens for 4 hours daily, and it is estimated that 12 biogas plants for cooking could save up to 444 hectares annually of natural forests from which firewood and charcoal are freely collected. In addition, the technology is environmentally sustainable in that the biogas plant captures about 30-40 percent of the total anthropogenic methane emissions, unlike firewood which contributes to emissions directly from combustion and indirectly through land use change (Chagunda et al., 2009).

Charcoal, gas and electricity are other sources of energy for households apart from fuelwood. As indicated above, these sources of energy serve only a small percentage of the population. The 1998 IHS data shows that in 1998, 2.4 percent of households considered charcoal as their main source of energy for cooking, while 0.79 percent and 0.04 percent of the households, respectively, considered paraffin and natural gas as their main source of energy for cooking (NSO, 2000). The recent 2004 IHS data show on the other hand that in 2004, 6.6 percent of the households now consider charcoal as their main source of energy, while 0.16 percent and 0.07 percent of the households, respectively, consider paraffin and natural gas as their main source of energy for cooking. In addition, about 1 percent of the households use crop residues as their main source of energy for cooking (NSO, 2005).

The 2004 IHS data also show that there are substantial rural-urban differences in terms of energy sources. For instance, charcoal is used by 44.3 percent of urban households as their main source of energy for cooking, compared with 43.7 percent that use fuelwood (Table 8). In rural areas, only 1.1 percent of the households use charcoal compared with 97.2 percent that use fuelwood as their main source of energy for cooking. Electricity, paraffin and gas are almost entirely for urban households while crop residues are important to rural households. However, the percentage of households that use paraffin, gas, saw dust and crop residues is negligible.

Table 8: percent of households by main source of energy for cooking and location

What is your main source of energy for cooking	Urban	Rural	Total
Fuelwood	43.7	97.2	90.4
Paraffin	1.0	0.0	0.2
Electric	10.0	0.4	1.6
Gas	0.5	0.0	0.1
Charcoal	44.3	1.1	6.6
Crop residues	0.1	1.2	1.1
Saw dust	0.4	0.0	0.1
Total	100	100	100

Source: Calculated by the author from 2004 IHS Data

However, not all households obtain their cooking energy through market channels. About 37 percent of households collect fuelwood from sources that may or may not require a payment of any form. Of these households, 9 percent collect fuelwood from own woodlots, 7 percent from community woodlots, 28 percent from forest reserves, 44 percent from unfarmed areas of the community, while 12 percent did not specify their source. Crop residues and saw dust were also cited by some households as important sources of energy for cooking (NSO, 2005).

2.5 The impact of biomass energy use on forest resources and cover

Historically, fuelwood availability and deforestation were not issues of national importance as energy and natural forest management were not given priority in national policy. At independence in 1964, about 47 percent of Malawi's surface area was classified as forest, against a backdrop of a population density of less than 45 persons per square kilometre. However, because of population growth and rapid expansion of agriculture and other sectors, forest area has since declined to 28 percent by 2000. This figure includes area covered by national parks and wildlife reserves (11.6percent), forest reserves and protected hill slopes (10percent) (GoM, 1996a). Currently wood demand is estimated to exceed supply by at least one third (GoM, 2001b) while national population density is now at 105 per square kilometre. However in some districts in the southern region, population density is over 200 persons per square kilometre (NSO, 2000). This trend is placing a tangible threat to sustainable management of forest resources and the main culprits are agricultural expansion and growing demand for fuelwood energy for both domestic and industrial use.

Forest resource degradation in Malawi could be attributed to unsustainable use of fuelwood to meet industrial and household energy needs. The fact that virtually all energy needs in Malawi are met from biomass sources implies a significant pressure on forest resources and cover. In the late 1970s to early 1990s, the pressure on forests was compounded by smallholder agricultural expansion which was only checked by supply constraint on cultivable land (GoM, 1998a). However, between 1990 and 2005, the country lost nearly 13 percent of its total forest cover due to fuelwood collection and subsistence and commercial agriculture. In addition, between 2000 and 2005 alone, the country lost almost 35 percent of its primary forest cover (Butler, 2006).

As a result of the extent of past forest resource degradation, the current deforestation rate in Malawi is estimated at 2.4 percent per annum (FAO, 2001; Fisher, 2004), but in some relatively high cover areas like the north of Malawi, the rate is estimated at 3.8 percent per annum (GOM, 1994a). This translates to about 33,000- 50,000 hectares of forests that are cleared every year to meet fuelwood demand (FAO, 2007; FAO, 2001; GoM, 2001a). Demand for fuelwood exceeds sustainable supply, and the deficit is growing at an alarming rate. The Forestry Annual Report of 2000-2001 estimates that the 1999 fuelwood deficit was 5.8 million cubic metres and that at the 2001 annual fuelwood demand growth rate, the deficit would reach 10 million cubic metres by 2010.

If left unchecked, fuelwood demand is eventually going to put pressure on forest reserves and on protected areas since most customary lands have literally been combed bare. Therefore, if deforestation and forest degradation continues without collective measures, the result will be environmental hazards, erosion of biological diversity, deterioration of wildlife habitat and degradation of water quality and quantity (FAO, 2003). It is therefore imperative to study the effect of policy changes especially those that recognise the importance of shifting the energy demand profile of households and industries from biomass base to more modern and less environmentally damaging energy sources like hydroelectricity and biogas.

Currently the government of Malawi through the Department of Energy and Department of Forestry has embarked on a program called Biomass Energy Strategy (BEST) as a response first of all to pressure on forest resources, and second to rural poverty. BEST falls under the European Union Energy Initiative for Poverty Eradication and Sustainable Development (EUEI) that was launched at the 2002 World Summit for Sustainable Development in Johannesburg. The strategy is meant to ensure a sustainable supply of biomass energy (mainly firewood and charcoal) and promote access to modern cooking fuels and efficient biomass combustion technologies by households and small enterprises (GTZ, 2007). BEST complements older and much broader initiatives such as MAREP, whose main focus was expansion of the national hydroelectricity grid to rural areas.

2.6 National environmental policy framework

Poverty and low access to electricity has greatly contributed to the over dependency on biomass energy and the over-exploitation of forest resources (GoM, 2002). Acknowledging the intricate relationship between economic wellbeing of the people and the environment, the National Environmental Policy (NEP) (GoM, 1994b) has as one of its guiding principles, the profound realization that Malawi's economy is highly dependent on natural resources, and that if these are depleted or degraded, long-term food security and sustainable economic growth would be seriously affected (NEP section 2.3 (e)). Section 2.3 (g) further states that "*Regulation will be complemented by social and economic incentives to influence behaviour for individuals or organizations to invest in sustainable environmental management*".

Malawi has more than forty separate statutes on the environment consolidated by the Environment Management Act (EMA) (GoM, 1996b). According to Part II, Sections 3-7 of the EMA, the custodians of the NEP and the EMA are the National Council for the Environment, the Technical Committee on the Environment, District Environmental Officers and District and Town Assemblies. District/Town Assemblies and City Assemblies are charged with local management of the environment. The assemblies have the authority to levy property taxes, charge fees for services rendered, make bylaws and impose penalties for non-compliance (GoM, 1998a).

The major environmental statutes include laws pertaining to land, forests, water, agro-chemicals, wildlife, and land use planning. The revision of some of the statues leading to the enactment of the EMA revealed major coordination weakness on crosscutting environmental issues. It was revealed for instance that most statutes had limited scope and content, making it difficult to identify parties responsible for environmental damages (GoM, 1994a). The revisions also showed a lack of sectoral policies needed to regulate or guide developments in certain aspects. In particular, there was a need for separate policies for land, water and forests, since the NEP was only a guiding document. A step towards more coordinated environmental policy was the enactment of the new Electricity Act in 1998 and later, the formulation of the

Integrated Energy Policy (GoM, 2003). These two documents, together with the National Forest Policy (GoM, 1996a) have focused on addressing problems in the energy sector.

2.6.1 National policies affecting energy supply and use in Malawi

Apart from the NEP (GoM, 1994b), the National Forest Policy (NFP) (GoM, 1996a), the Electricity Act of 1998, and the Integrated Energy Policy (GoM, 2003) are the main policy documents that directly or indirectly address energy problems in Malawi. These documents spell out the sectoral priorities as well as the socioeconomic underpinnings that precipitated the various strategic policy statements that they contain.

Section 5.6 of the NEP outlines some of the guidelines that the government of Malawi is following in implementing the national energy strategy. The policy recognises externalities associated with energy use, especially fossil based energy sources. In particular, the policy states that "*environmental externalities of all energy sources shall be identified and incorporated into policy design and project costing*" (GoM, 1994b: section 5.6 (a)). It also aims at minimizing dependence on imported oil as alternatives are explored, in addition to finding alternative energy systems to fuelwood for both rural and urban communities in Malawi. Further the provision of infrastructure for rural electrification is viewed as a social service since it could significantly arrest deforestation, and improve the quality of rural life (GoM, 1994b: section 5.6 (b)-(f)).

Other policies like the National Forestry Policy and the Integrated Energy Policy equally stress the need to develop alternative energy sources especially for rural communities. The general objective of the NFP is to satisfy people's many diverse and changing needs, particularly those of the rural people who are the most disadvantaged. Specifically the policy aims at "*providing an enabling framework for promoting the participation of local communities and the private sector in forest conservation and management, eliminating restrictions on sustainable harvest of essential forest products by local communities, and promoting planned harvesting and regeneration of the forest resources by Village Natural Resources Committees (VNRC's)*" (GoM, 1996a: Section 2.3.1).

The establishment of VNRC's under the NFP is important because there are vast areas of forests on customary land estimated at about 3.1 million hectares that fall under the jurisdiction of traditional chiefs. At the time the NFP was being drafted, customary land forests accounted for 17 percent of the country's land area under forest cover (GoM, 1996a: Section 1.5). Overall, the NFP envisages a shift in the country's energy mix through institutional changes and economic incentives. Section 2.3.11 for instance outlines the specific objective of the NFP as that of reducing dependence on fuelwood as a source of energy through *inter alia*, (i) promoting "*methods and techniques for the utilization of alternative sources of energy to substitute fuelwood*" (section 2.3.11.1), and (ii) initiating the "*provision of incentives to promote uses of alternative sources of energy*" (GoM, 1996a: section 2.3.11.3).

The first edition of the Integrated Energy Policy (IEP) for Malawi was released for public debate towards the end of 2001. The policy aims at promoting socioeconomic development and contributing to poverty reduction through sustainable provision of "*equitable, efficient and affordable energy service*" (Chilipaine, 2006). The IEP moots rural electrification as a bold step towards addressing both, the energy needs of the rural poor and the environmental consequences of forest resource depletion for energy. Steps towards rural electrification have also included the enactment of a new Electricity Act in 1998, repealing the antiquated Electricity Act of 1965 which established ESCOM as the sole generator and distributor of electricity in Malawi.

Under the new Electricity Act, "Commission" becomes "Corporation", thereby establishing a commercial entity with the same acronym, ESCOM, whose role remains generation, transmission and distribution of electricity. However, the 1998 Act allows for new entrants in the electricity market by establishing a National Electricity Council (NECO) responsible for licensing and regulating power producers. In addition, the revised IEP (GoM, 2003) addresses some of the issues that were not fully addressed by the first edition of IEP of 2001. In particular, the revised energy policy sets procedures for third party access to the national power grid, establishment of a pricing committee, and financing and regulation of investment in alternative energy sources such as fossil fuels and solar energy.

NEP and IEP are therefore in agreement to the extent that both view prices as important in influencing behaviour of both firms and households. In particular, while establishment of a pricing committee is the mandate given by IEP, chapter 3 of NEP, section 2 lays down the guiding principles for pricing. In particular, section 3.2 (c) states that "*Priority will be given to establishing an enabling economic environment in which market prices provide appropriate incentives for sustainable natural resource use and environmental protection*", and section 3.2 (d) states that "*Prices should reflect opportunity costs and externalities.*" Also section 3.2 (e) states that "*Market failure with regard to the pricing of natural resources will be corrected through the assessment of user fees and taxes or the use of tax reductions and other incentives.*" Finally, section 3.2 (f) gives government departments and local communities the right to revenue generated from sustainable utilization of natural resources on public and customary lands in order to provide positive incentives and self-finance for such continued use.

2.6.2 Expected future developments in environmental and related policies

The Malawi government currently allocates less than 2 percent of its total budget (or less than 1 percent of the economy's GDP) on environmental protection and conservation. In contrast, there is no equivalent revenue collected from environmental regulation activities. Ideally, the government is expected to adjust the costs of environmental management with fiscal revenues generated from taxing activities benefiting from or polluting the environment. It is accordingly projected that future developments in environmental policy would incorporate tax reforms aimed at balancing the environmental fiscal costs and benefits.

Currently, income and profit taxation dominate with an annual average contribution of 42 percent to tax revenue. Taxation of goods and services is the second most important source of tax revenue contributing an average of 41 percent annually, which is an increment from an average of 36 percent between 1995 and 2000. International trade taxes on the other hand are becoming less important for revenue due to SADC, COMESA and other bilateral and multilateral trade agreements. As a result of several international trade agreements, there have been several reductions in maximum tariff rates from 45 percent in the early 1990s to about 25 percent in the 1998/99 budget (GoM, 1999). Currently, the contribution of international trade taxes to tax revenue averages 16 percent annually between 2001 and 2007 (Table 9).

Table 9: Central Government Revenue (%) by source

	2001	2002	2003	2004	2005	2006	2007*	Average
Gross Tax Revenue (Million MKW)	20286.0	23486.0	31749.0	42476.0	55822.8	68177.9	57953.3	42850.1
Taxes on Income and Profits	42%	44%	40%	42%	42%	42%	45%	42%
Taxes on Goods and Services	46%	37%	45%	44%	41%	40%	37%	41%
International Trade Taxes	12%	19%	15%	15%	17%	18%	18%	16%

Source: Ministry of Finance Annual Economic Reports, Note: * Monthly data available up to August 2007.

The tax reforms aimed at incorporating environmental concerns would have to consider the efficiency and distribution effects of such reforms. The imposition of a tax on an activity will, in general, reduce welfare of the taxpayer. The issue that arises is how marginal tax rate increases influence actions of economic agents. Some taxes are particularly distortionary because they impose a burden over and above the revenue that they are supposed to raise (Widmalm, 1999). The prospect for environmental fiscal reforms and the search for optimal energy mix under is subject of a later chapter.

2.7 Chapter summary

The chapter discussed the Malawian economy in terms of (i) economic structure and performance, (ii) aggregate energy use and supply the, (iii) energy demand by production activities and households, (iv) implications of energy use profile on forest resources and forest cover, and (v) national environmental and energy policies. The chapter has revealed that the energy profile of the economy mainly consists of biomass sources, and that, although Malawi has a large installed hydroelectric capacity, its supply strategy which is biased towards industrial users has failed to tap into the large demand for energy from households. To remedy the situation, the IEP proposed the expansion of infrastructure to rural areas in a bid to shift demand from biomass sources to more efficient hydro-energy.

The chapter also revealed that Malawi remains an agricultural driven economy in terms of employment, contribution to GDP and exports. Further, the manufacturing industry has been shown to rely heavily on agriculture, a situation that increases the country's macroeconomic vulnerability to the same risks that agriculture as a sector faces. There are however prospects that Malawi might diversify into non-agricultural sectors such as mining, services and construction.

The IEP, together with the NEP have been heralded as the twin agents of change in the energy sector. In particular, through the IEP, and the subsequent passing of the Electricity Act (GoM, 1998b), rural electrification has started to be implemented in phases. However, rationalization of prices through fiscal measures and regulation as envisaged by both the IEP and NEP are yet to be experimented with. The delay may reflect the fact that policy makers are yet to be convinced that the new price and fiscal reforms aimed at incorporating environmental concerns in the energy sector would result in the intended efficiency and distribution effects purported by IEP and NEP.

CHAPTER 3: REVIEW OF APPROACHES TO STUDYING SECTORAL ENERGY INTENSITIES AND ENERGY SWITCHING POLICIES

This chapter reviews energy economics as it relates to industrial production and household consumption, and how economists have studied policies aimed at encouraging a switch from one source of energy to another. Section 3.1 reviews the theory of production and how energy enters production relationships. It also discusses how technology may determine energy efficiency. Approaches to studying sectoral energy intensities and switching policies are reviewed in section 3.2. The section also discusses theoretical and empirical issues that arise in partial equilibrium and general equilibrium approaches. Section 3.3 introduces energy as a consumer good and section 3.4 reviews approaches to studying household energy demand and substitution possibilities. The section focuses on the household production and the random utility frameworks. Section 3.5 provides a synthesis of the reviewed literature and concludes the chapter.

3.1 Energy as a factor input

There are two basic definitions of energy that are relevant to economic theory of production. The first comes from physics, and describes energy as the capacity of matter or radiation to perform work. The second, and closest to everyday language usage, refers to energy as the power derived from physical or chemical resources to provide light and heat or to work machines (Oxford English Dictionary, 2001). Energy in the latter sense is often transformed into homogeneous physical units such as the British thermal units (Btu), combining various energy inputs into aggregate or separate units. Thompson (2006) refers to such a homogeneous physical unit of energy, E, as produced energy which required capital (K), labour (L) and a natural resource input (N) to convert into energy:

$$E = E(K, L, N) \qquad (3.1)$$

Further, energy is embodied in products through the generic production function of the form

$$y = f\left(z, E(K, L, N)\right) \tag{3.2}$$

Where $z = (z_1, z_2, ..., z_n)$ is a vector of primary and intermediate inputs other than energy, and y is gross output.

Presented as above, final energy consumption is mainly attributed to production activities, implying that an increase in final demand for goods and services would result in an increase in final energy consumption for any given technology (Ferng, 2002). However, if energy is a produced commodity available for final consumption, some energy would be demanded by households either separately or as a complement of some other commodity in household consumption. At macro level, the gross output of the energy sector must either be used up in the production of other goods and services (as intermediate input) or it must be absorbed by final demand sectors. Since the behavioural aspects of demand for produced energy is considered important for policy analysis, the next section outlines the theoretical aspects of energy demand by production sectors.

3.1.1 Energy in production

The standard production problem starts with an economic unit or entity (typically a firm) that transforms a set of different types of inputs into one or more outputs. The mapping from inputs to outputs is usually summarised using a production function which delimits the technical constraints of the representative firm. Generalizing equation 3.2 above, the technological constraint of a firm can be defined as follows:

$$0 \leq y \leq f(z, E); \quad z, E \geq 0 \tag{3.3}$$

Where z, and E are as defined earlier, except that E might have a different technology than the one implied by equation 3.1. Equation 3.3 states that a firm would, with positive inputs, produce at least some given level of positive output.

A technological delimitation that a firm might face is that of essentiality of energy. There is strict essentiality if it is impossible to produce output without using any form of energy, implying that:

$$f(z,0)=0 \tag{3.4}$$

Energy, just like all other factors of production has derived demand. Energy is demanded conditional on the firm's chosen output level and technology used. Assuming that the firm is a profit maximizing entity that faces exogenous input prices, the firm's cost minimization problem can be given by:

$$\min_{z_1,\cdots,z_n,E} C(w,e,y)=\sum_{i=1}^{n} w_i z_i + eE \qquad s.t.\ (i)\ f(z_1,\cdots,z_n,E)\geq y$$
$$(ii)\ z_i \geq 0$$
$$(iii)\ E \geq 0 \tag{3.5}$$

Where w_i = unit price of input i

e = unit price of energy input

z_i = amount of input i

Since a profit maximizing firm would choose only that bundle of inputs which minimizes the total cost of producing a given level of output, the derived demand for inputs, including energy, depends on the level of output, the substitution possibilities among inputs implied by the production function, and the relative prices of all inputs (Berndt and Wood, 1975). Using Shephard's duality theorem (Humphrey and Moroney, 1975; Woodland, 1993), the partial derivative of $C(w,e,y)$ with respect to e gives the conditional energy demand, $E(w,e,y)$. Similarly, the partial derivative of $C(w,e,y)$ with respect to w_i gives the conditional input demand $z_i(w,e,y); \forall i=1,\cdots,n$.

The concern with the elasticity of substitution between capital and energy was considered important following the world oil crisis in the 1970s in view of uncertainty regarding future energy prices and availability. It was believed for instance that if capital and energy are complements, increases in prices would perhaps induce a reduction in the demand for capital goods, thereby stifling growth. On the other hand, if capital and energy are substitutes, rising energy prices would stimulate demand for capital (Thompson and Taylor, 1995; Berndt and

Wood, 1975). In general, the outcome of decisions regarding energy policy depends heavily on substitution between energy and other factors of production. However, literature on energy substitution offers no consensus regarding specification, size and direction of change due to relative prices (Thompson, 2006).

The Allen relative elasticity of substitution (RES), also called the Hicks-Allen elasticity of substitution, measures the responsiveness of relative inputs to relative input prices. The RES between inputs i and j is the percentage change in relative input factor i with respect to the change in the relative price of factor j (Thompson, 1997):

$$RES_{ij} = \frac{\partial \ln\left(z_i / z_j\right)}{\partial \ln\left(w_j / w_i\right)} \qquad (3.6)$$

Where the z's are cost-minimizing inputs per unit of output and w's are input prices.

Allen (1938) showed for constant returns to scale production function $y = f(z)$ that the partial elasticity of substitution can be expressed as:

$$\pi_{ij} = \frac{yF_{ij}}{z_i z_j F} \qquad (3.7)$$

Where F is the bordered Hessian matrix of partials and cross partials of the production function, and F_{ij} is the cofactor of the element i, j.

The Allen partial elasticity of substitution is inappropriate in energy studies because of the problem of economic interpretation. In particular, with three or more inputs, the percentage change in the relative input of factor i due to a change in the relative price of factor j is a meaningless statistic that holds all other inputs constant, when in fact all inputs adjust to any change in factor prices (Thompson, 2006). There are other reasons favouring alternative measures of elasticities to the Allen partial substitution elasticity in energy studies. Thompson and Taylor (1995) noted that for inputs such as energy that usually consist small cost shares, relatively small changes in the use of the input can induce large changes in Allen partial elasticity estimates. In addition, Allen partial elasticities are relatively less robust to levels of data aggregation in empirical applications (Shankar et al., 2003).

Welsch and Ochsen (2005) used the Morishima elasticity of substitution (MES) to measure substitutability between capital and labour, between capital and energy and between labour and energy. The MES measures the negative percentage change in the ratio of input i to input j when the price of input j alters. Blackorby and Russell (1989) define the MES between inputs i and j in a production function with many inputs as:

$$MES_{ij} = \frac{\partial \ln(z_i / z_j)}{\partial \ln w_j} \tag{3.8}$$

And cross-price Morishima elasticity of substitution (CMES) as:

$$CMES_{ij} = RES_{ij} - RES_{jj} \tag{3.9}$$

The MES is a generalization of the two-factor elasticity of substitution to the case of multiple (>2) inputs. An input j is a Morishima substitute (complement) for input i if MES_{ij} > (<) 0 (Blackorby and Russel, 1989; Welsch and Ochsen, 2005). From (3.8) above, relative input price changes are not explicitly considered in the Morishima elasticity, although the cross-price elasticity shows a clear relationship between the Morishima and the Hicks-Allen relative price elasticity of substitution.

Thompson (1997) also considers the MacFadden elasticity measure in addition to the Allen (1938) and Morishima elasticities. The MacFadden elasticity allows for change in relative input price but holds cost constant (the cost-minimizing envelope). Taking the total differential of the cost function $C(w,e,y) = \sum_{j=1}^{n} w_j z_j + eE$, when only the prices of inputs i and E change, we get:

$$dC = 0 = \sum_{j=1}^{n} z_j dw_j + Ede = \theta_i \hat{w}_i + \theta_E \hat{e} \tag{3.10}$$

Where $-\frac{\theta_i}{\theta_E}=\frac{\hat{e}}{w_i}$, the percentage change in relative inputs, and the circumflex represents percentage change. The MacFadden shadow elasticity is expressed as half the weighted average of the two relevant Morishima elasticities

$$\phi_{iE}=\left.\frac{d\ln(z_i/E)}{d\ln(e/w_i)}\right|_{dC=0}=0.5\frac{(\theta_i MES_{iE}+\theta_E MES_{Ei})}{(\theta_i+\theta_E)} \tag{3.11}$$

3.1.2 Energy intensity and efficiency

Apart from the implications of substitution possibilities between energy and non-energy factors, energy economics studies have also focused on efficiency of energy resource use by production activities. Energy efficiency is often defined in terms of energy intensity of a production activity. Energy efficiency improves if the energy intensity, i.e., the quantity of energy required per unit of output or activity, falls over time (Markandya et al., 2006). Energy intensity could therefore be interpreted as measure of single factor productivity similar to average output, since it is a ratio of output to the input of energy.

There is however some dissatisfaction with the quality of energy intensity indicators in literature. Freeman et al. (1997) quotes a US Department of Energy study which found that energy intensity in manufacturing had increased by 4.5 percent between 1988 and 1991 while when a value-based measure of output was used, energy intensity declined by 12.7 percent over the same period. Apart from differences in output measures used in literature, there are also differences in choice of unit of measurement of energy. For instance, the definition of energy intensity adopted by Markandya et al. (2006) uses tons of oil equivalent per 2000 purchasing power parity (PPP) dollar, while other studies measure energy intensity as Btu per unit of economic activity (value added or gross output).

Berndt (1978) proposed that energy efficiency should be analysed in the larger context of energy and non-energy inputs than just looking at energy-output ratios. Such a framework would allow analysis of issues such as the effect of energy price increases on tradeoffs between energy and labour in production. However, aggregating over a number of fuels to come up with one estimate of energy use per activity is unsatisfactory even after introducing non-energy inputs in the analysis. In particular, Berndt (1978) argues that aggregating over energy types to obtain the total Btu demand and supply forecasts is problematic because energy types are to some extent substitutable in end-use demands. In addition, the price per Btu of the various primary and secondary energy products is not equal among energy types.

Regardless of problem with the current energy efficiency measure, it is recognised in literature that energy efficiency is both an environmental and economic concern. From the environmental viewpoint, energy efficiency may be adopted as a policy goal in a bid to conserve or slow down the depletion of fossil fuel reserves. Complementary to the first goal is the reduction in greenhouse gas emissions related to fossil fuel use. From the economic point of view, energy efficiency may also be interpreted in terms of minimizing costs in the face of rising energy prices (Mukherjee, 2006). However, from the economic point of view, it is recognised that changes in energy intensity in production may not necessarily reflect underlying trends in technical efficiency, but rather changes in the structure of the industry (Freeman et al., 1997; Garbaccio et al., 1999). Further, the change in industrial composition may be as a result of international trade effects which induce energy saving on the economy (Welsch and Ochsen, 2005).

3.1.3 Technology as a determinant of energy intensity

If energy efficiency is interpreted as declining industrial energy intensity over time, there is a *prima facie* case for associating the state of technology with industrial energy intensity. According to projections from the International Energy Agency data, fossil based fuels will account for more than 90 percent of world primary energy demand up to 2010, and probably up to 80 percent in 2020 (IEA,2003). However, it is often assumed that technological advancement will generally lead to a reduction in some forms of energy use, especially fossil fuels because they are considered environmentally damaging, and/or economically wasteful.

Developing countries use fuels less efficiently than industrialized countries because of lack of state-of-the-art technology. According to Sathaye and Ravindranath (1998), fuel efficiency is also compromised because of the proportionately higher use of coal and biomass which produce more carbon dioxide per unit of energy than do petroleum products and natural gas. It is also suggested that capital intensive production activities in developing countries are the ones that demand proportionately more carbon-intensive fuels than labour intensive activities. It is therefore expected that energy policies would be key in determining not just energy market developments in developing countries but also economic growth and welfare (Solsberg, 1997).

There are several reasons for proposing that capital intensive sectors in developing countries are also energy intensive. The first reason is that at low levels of economic development, many of developing country plant and machinery are operated at excess capacity and are thus not energy efficient. Second, even where modern plant and machinery have been adopted, economic development may increase demand for goods and services to levels that erode the gains from adopting energy-efficient technologies. The second reason is called the rebound effect and it occurs when proliferation of energy-efficient technologies achieve substantial cost savings on energy services whose general equilibrium effects are increased demand for energy services and greater energy consumption as the savings are spent elsewhere in the economy (Jaccard and Associates, 2004; Boonekamp, 2007;Takase et al., 2005).

Policies aimed at stimulating energy efficiency in production may have one of two possible impacts on individual firms depending on whether or not a firm was producing at full employment. If a firm were operating below full employment, it could significantly reduce energy use without loss of output. Does this mean that it is possible for a firm to adjust employment of energy and other inputs at zero cost? If on the other hand production was already energy efficient, any policy designed to reduce energy use would necessarily raise the cost of producing a given level of output as energy prices are increased (Thompson, 2000; Smulders and de Nooij, 2003; Klepper and Peterson, 2006).

In the likely event that cost of production rise with the implementation of energy policies, energy studies quantify the magnitude by which costs rise. The direct impact of energy price changes would depend on the ease of substitution between energy and non-energy inputs, which in turn depends on the state of technology. Therefore, to avoid loss of output or to counteract rising production costs, a profit maximizing firm would either embark on a radical technological innovation (adoption of a completely new technology) or an incremental innovation to the existing technology. However, the former type of innovation is rarely observed in reality because of the presence of uncertainty (Jaccard and Associates, 2004).

In policy analysis, a distinction can be made between policies that reduce the level of energy use from those that reduce the growth rate of energy inputs. Although both policies may stimulate innovation, they have the unsavoury characteristic of reducing output levels. According to Smulders and de Nooij (2003) technical change should be viewed as an endogenous variable whose evolution is induced directly through changes in energy prices, or indirectly through innovation when a firm takes up energy saving technologies. A similar view to the one held by Smulders and de Nooij is presented in an endogenous growth theoretic framework by Otto et al. (2006) who developed a general equilibrium framework that links energy, the rate and direction of technical change and the economy.

The dichotomy between energy policies that reduce the level of energy use and those that reduce the growth rate of energy inputs is rather blurred in practice. According to Pindyck (1979), most energy studies have focused on isolating the substitutability of energy and other factors of production when examining the effect of GNP growth and changes in fuel prices on industrial demand for energy. However, one can also focus on substitutability of fuels within the energy aggregate (Mountain, 1989; Woodland, 1993; Jones, 1996). The distinction between elasticity of substitution among fuel types in the energy aggregate and elasticity of substitution between energy and non-energy inputs becomes important when firms generally use different production technologies.

The importance of both technology and elasticities in applied energy studies stem from the fact that elasticities determine the economic costs of technology adaptation under energy policy constraints. If energy and capital are substitutes, higher priced energy would *ceteris paribus*, increase demand for new capital goods. Also, limited substitutability between energy and non-energy inputs could be reflected in high adjustment costs by firms to higher energy prices as significant technical changes may be required (Berndt and Wood, 1975). Elasticities are also crucial in determining the rate of an environmental tax and subsidy that would attain a given environmental target (Pindyck, 1979; Klepper and Peterson, 2006; Kemfert and Welsch, 2000).

3.2 Approaches to studying sectoral energy intensities and switching policies

3.2.1 Nonparametric and parametric partial equilibrium models

Mukherjee (2006) used data envelopment analysis (DEA) to examine energy efficiency in manufacturing sectors for the period 1970 to 2001. DEA recognises that multiple inputs are used in the production of output, and thus allows input substitutions. Efficiency is measured based on an intertemporal production possibility frontier. With DEA, the concept of energy intensity is now replaced with that of a set of all possible input bundles that could produce a given level of output. Efficiency is therefore measured by comparing the actual level of either inputs or outputs against a minimum value implied by the inputs feasible set or maximum output value implied by the production possibility frontier. The input-oriented technical efficiency is defined as the ratio of optimal (minimum) input bundle to the actual input bundle of a decision making unit (DMU) for any given level of output, holding input proportions constant. The output-oriented technical efficiency is implicitly defined as the ratio of the observed output to the optimal (maximum) achievable output.

Garbaccio et al. (1999) used decomposition analysis to explain a 55 percent reduction in energy use per unit GDP in China between 1978 and 1995. The fall in energy use was decomposed into technical change and various structural changes including changes in quantity and composition of imports and exports. Technical change within sectors accounted for most of the fall in energy-output ratio while structural change actually increased energy use. It was also found that imports of energy-intensive goods lowered energy-GDP ratios. However, the level of aggregation for sectoral inputs and outputs was considered crucial for distinguishing the impact of technical and structural factors on energy-output ratios.

Descriptive decomposition studies are criticized for failing to identify sources of energy efficiency improvements and energy saving structural change. It is therefore not possible within the framework of descriptive decomposition to conduct a joint assessment of factor substitution and technological change. In the end, there is ambiguity as to whether changes in energy intensity are a result of technological factors (energy efficiency due to factor substitution and/or biased technological change) or structural factors (composition of aggregate output due to international trade effects). According to Welsch and Ochsen (2005) the alternative is to estimate factor share equations which in a way endogenize factor prices.

Estimates of interfuel elasticity of substitution have been empirically obtained using various specifications. The two most common specifications are the translog cost function and the linear logit cost share function. The translog function was developed by Christensen et al. (1973) and became popular over Cobb-Douglas specifications because it placed no *a priori* restrictions on Allen elasticities of substitution. It is however, Pindyck's (1979) translog model of capital-labour-energy aggregates that has been extensively adopted by various studies of energy demand.

Berndt and Wood (1979) interpreted and reconciled the contradictory evidence in literature regarding substitution possibilities between energy and capital. For instance, Berndt and Wood (1975) found complementarity between energy and capital in time series data while Griffin and Gregory (1976) and Pindyck (1979) found substitutability between energy and capital in pooled time series data. The conclusion by Berndt and Wood (1979) was that differences in results were partly due to differing data sets used, approaches to measuring input quantities and prices, treatment of excluded inputs and distinction between short-run and long-run elasticities. In addition, energy-capital complementarity based on time series data reflected short-run variations in capital utilization but the true long-run was one of energy-capital substitutability as found by Griffin and Gregory (1976) and Pindyck (1979). Thus, pooled cross-section time series elasticity estimation should be more realistic compared to elasticities estimated solely on time series data (Griffin and Gregory, 1976; Pindyck, 1979).

The issue of capital-labour-energy (KLE) substitution is however surrounded by uncertainty over the appropriate technological representation and numerical values for substitution elasticities (Kemfert and Welsch, 2000). The importance of both technology and elasticities in applied energy studies stem from the fact that elasticities determine the economic costs of technology adaptation under energy policy constraints. Elasticities are also crucial in determining the rate of an environmental tax that would attain a given level of environmental quality target (Pindyck, 1979; Klepper and Peterson, 2006; Kemfert and Welsch, 2000).

Pindyck (1979) used a translog cost function that is homothetically separable in the KLE aggregates. Although estimated at macro level, the cost function is consistent with microeconomic behaviour of cost minimization at two levels namely, the energy aggregation stage where the choice of fuel inputs minimize cost of energy input, and the output aggregation stage where the choice of KLE minimizes the cost of production. The model allows for cross-price effects of energy and non-energy inputs, as well as among individual fuels in the energy aggregate.

Earlier studies of aggregate input substitution like Berndt and Wood (1975), Pindyck (1979) and Griffin and Gregory (1976) relied heavily on separability assumption which is equivalent to placing restrictions on Hicks-Allen partial elasticity of substitution and price elasticities. According to Berndt and Christensen (1973a) use of capital and labour aggregates implies stringent separability restrictions on neoclassical production function or equivalently, that there exists a price aggregate for the weakly separable components of the aggregate inputs. Blackorby and Russell (1981) later developed equivalent restrictions for Morishima elasticity of substitution. According to Berndt and Christensen (1974), little information is lost by aggregating inputs if within each aggregate factors are highly substitutable for one another. Also, factor intensities can be optimized within each separate subset of a function on which certain equality restrictions on Allen partial elasticities of substitution hold (Berndt and Christensen, 1973b).

Other studies avoid the aggregation issue by including components of a subset in the estimation equation. Woodland (1993) for instance, used a translog system for coal, gas, electricity, oil, labour and capital as production factors. Unlike Pindyck's (1979) macroeconomic approach, Woodland used a repeated cross-section of companies observed from 1977 to 1985. Woodland also estimated separate translog functions for each observed energy patter (i.e., energy mix used by a company) on the assumption that the energy mix in a company was exogenously determined by technology.

There are however concerns about the appropriateness of the translog specification in energy studies. Compared with the linear logit model, the translog cost functional form has the potential to produce negative cost shares because it fails to satisfy regularity conditions (concavity) for negative own-price effects over the relevant range of fuel prices (Jones, 1996). Although the validity of concavity assumption depends both on functional form and the dynamic specification of the adjustment of producer behaviour, and could be tested ex-post, Urga and Walters (2003) found that the translog specification violated the concavity conditions in most cases. In particular, the translog specification does not guarantee positive cost shares and negative own-price effects. Also, unlike the linear logit model the translog cost function fails to meet the Le Chatelier principle, i.e., long-run direct price effects are never smaller than the short-run effects.

The dynamic linear logit model performs particularly well in applied energy studies. Jones (1999) used a dynamic linear logit model that estimates theoretically consistent fuel price elasticity, i.e., negative own-price effects and positive cross-price elasticities between fuels (for substitutes). The model also gives a direct estimate of the rate of dynamic adjustment to fuel price changes that is consistent with the Le Chatelier principle. The rate of adjustment is important as it relates to two main costs associated with energy policy changes. First, there are costs associated with the extra emissions during the transition from carbon-intensive fuels to cleaner fuels. Second, there are economic as well as investment costs that must be incurred as firms change their fuel technology.

There are other theoretical and empirical benefits from using the linear logit specification. In particular, the linear logit specification allows the estimation of nonlinear Engel curves, and partial adjustment mechanisms without placing undue restrictions on the input structure (Considine, 1990; Considine and Mount, 1984). The input shares satisfy the adding-up and non-negativity conditions consistent with neoclassical demand theory (Shui et al., 1993), and symmetry of the second partial derivatives of the cost function could be defined for each set of cost shares in a sample (Considine, 1990). In addition, the demand systems are continuous and thus subject to the same restrictions as the translog and CES cost functions (Brannlund and Lundgren, 2004; Atkinson and Halvorsen, 1976).

Despite the advantages that linear logit model has, there are econometric problems associated with the share demand formulation. In particular, the linear logit model leads to misleading inferences arising from the presence of prices on both sides of the equation (Hsiao and Mountain, 1989). Further, although the autoregressive nature of the error term of the logit model can be established ex-post (Chavas and Segerson, 1986; Considine, 1990), the distribution of the error term may not be consistent with the assumption of normality. Thus statistical hypotheses from linear logit models may be misleading (Mountain and Hsiao, 1989).

Thompson (2006) reviewed the applied theory of energy cross-price partial elasticities of substitution using regression analysis. The most important conclusions from the reviewed theory are that: (i) estimates of cross-price substitution are sensitive to the industries and regions of study, (ii) choice of functional form may affect estimated cross-price elasticities, (iii) time periods chosen and the dynamic model of substitution are critical due to path dependencies that arise given fixed cost of input adjustments and (iv) substitution involving an aggregate is not necessarily a weighted or other average of the disaggregated inputs.

Thompson (2006) also presented a duality theory based on log-linear (Cobb-Douglas) and translog specifications from which cross-price elasticities were specified and estimated.

Welsch and Ochsen (2005) estimated share equations for energy, capital, low-skilled labour, high skilled labour and materials. The focus of the study was on factor substitution between energy and capital in a translog cost function for aggregate gross output. The share equations were estimated using the method of iterated three stage least squares which is a special case of generalized method of moments (GMM). The study concluded that materials, capital, and low-skilled labour are Morishima complements to energy. They also concluded that energy is a Morishima substitute for all other inputs except materials, whereas all inputs are Morishima complements to energy.

The finding by Welsch and Ochsen (2005) that capital is a Morishima complement to energy differed significantly from previous findings in the 1970s and 1980s that capital is a Morishima substitute for energy (Thompson and Taylor, 1995). Welsch and Ochsen (2005) explained their result by noting that most of the earlier studies focused on manufacturing, whereas their study refers to overall production (aggregate data). Thus, while substitutability may prevail in manufacturing, the overall production function may be characterised by capital being a complement to energy. In addition, temporal differences in data coverage may have influenced the result. For instance, their energy data comprised a higher share of electricity than previously used data sets, which may actually imply that while capital might have been a substitute for fuels, capital was more likely to be a complement to electricity.

3.2.2 General equilibrium models of energy substitution

Leontief (1970) showed that economic systems and the environment are linked starting from natural inputs that enter production or consumption relationships. Leontief's idea was later extended to emissions that could feedback to the economy through production technologies and consumption functions (Mestelman, 1986). Others studies including Ferng (2002) and Kratena (2004) considered energy as fundamental to pollution analysis because biomass and fossil energy are the main sources of anthropogenic perturbations of the ecosystem carbon cycle. Kratena (2004) even suggested the use of energy as a 'numeraire' for ecosystems flows since energy is needed to drive the biogeochemical cycles in ecosystems.

The 1973 oil price shock provided the first impetus to the development of general equilibrium models for energy policy analysis. The first energy policy analyses focused on energy demand and supply options, but recently, the focus has shifted to environmental pollution (Bhattacharyya, 1996). With rising energy prices and uncertainty over future energy availability, energy policy issues that came to the fore were price formulation, output determination, income generation and distribution, consumption behaviour, government operation and reducing emission of greenhouse gases associated with energy use.

Within the framework of applied general equilibrium (AGE) modelling the major aim is to measure the overall economic impacts in any economy of changes in the energy sector. While the first studies concerned themselves with technological change and how to represent substitution between energy and non-energy inputs, the focus has shifted to problems associated with the supply of energy and the external effects associated with the use of energy, particularly fossil fuels at the beginning of the 1990s (Bergman and Henrekson, 2003).

There are at least three AGE modelling approaches discussed by Bhattacharyya (1996) that are relevant to energy economics. The first AGE modelling strategy due to Hudson and Jorgenson (1974) uses econometrics to estimate parameters of a general equilibrium system. The Hudson and Jorgenson (1975) energy study in particular, was aimed at examining how relative product and factor prices, and the allocation of resources might be affected by factors such as increasing energy costs, technological change in the energy sector or various energy policy changes. The paper assumed that capital and energy were substitutes other than complements, although the elasticities of substitution were less restrictive. Elasticities were econometrically estimated using constant returns to scale translog price possibility frontiers.

The most common specification of production technology in studies following the Hudson and Jorgenson (1974) approach is the ‘nested’ CES function that includes the KLE factors. These functions are estimated econometrically to obtain elasticities that are incorporated into general equilibrium models or other policy analyses. Kemfert and Welsch (2000) test three CES specifications, all with a neutral technical progress factor: (i) a two-level CES function with E/K composite substituting labour, (ii) a two-level CES function similar to the specification used by Manne and Richels (1992) with K/L composite substituting energy, and (iii) a two-level CES function with L/E composite substituting capital. From the empirical results Kemfert and Welsch (2000) conclude that a nested CES production with a composite of K/E seemed more appropriate for aggregate production function, although their disaggregated sectoral production functions had mixed results.

Bohringer (1998) used a simple separable nested CES functions to capture technology information on energy system in production. The purpose of the study was to compare and integrate elasticity based computable general equilibrium (CGE) models (top-down) and 'true' technology based activity analysis (bottom-up). The top-down CGE approach uses price dependent point-to-point continuously differentiable functions for which a Walrasian general equilibrium exists at which no firm earns excess profits and all output is allocated. To integrate bottom-up approaches, discrete Leontief technologies are specified for lower level activities. For energy economics studies, however, the top-down approach is more appropriate because it uses microeconomic models with detailed representation of the energy sector unlike the bottom-up approach which appeals to engineering search for different technical potentials for achieving set targets such as emission reductions (Klepper and Peterson, 2006).

The main advantage of the Hudson and Jorgenson (1974, 1975) approach is that endogenous relative energy price (response) functions are derived within a framework that allows for endogenous technological change. The model accommodates complementarity between two types of inputs as well as different partial elasticity of substitution between pairs of inputs, which are ruled out by technology constraints represented by CES and Cobb-Douglas production functions (Bergman, 1988).

The Hudson and Jorgenson approach requires annual time series data and thus the estimated elasticities are short run. The problem with short-run elasticities however, is that they understate the response capacity of agents when a longer adjustment period is considered. Also, the large number of parameters to be estimated would require long time series if the BLUE properties of the estimates are to be maintained. Structural changes during the time over which estimates are generated may also not be reflected in the parameters, and the parameters are generally not adequate because they are obtained without imposing the full set of general equilibrium constraints. In addition, lack of data, computational and conceptual difficulties in estimation and uncertainty concerning the validity of resulting estimates limits the applicability of the econometric approach in developing countries (Arndt et al., 2002).

The second approach due to Johansen (1960, 1974) follows the multisector growth model (MSG). The MSG assumes fixed input-output coefficients for intermediate inputs, log-linear or Cobb-Douglas production function for value added (mainly, labour and capital), and one representative household. Later variants of the original MSG introduce sectoral disaggregation and the Armington assumption for international trade. The model solution is found by calibrating the values to their base year.

Similar to the Hudson and Jorgenson (1975) approach, the MSG incorporates substitution possibilities between KLE and materials (M) aggregates. However, the substitution responses are represented by generalized Leontief cost functions interpreted as second order approximations to the underlying production structure (Bergman, 1988). Hence the MSG shares the same weakness as the Hudson and Jorgenson (1975) model. In addition, the MSG has the restrictive assumption of a representative household, which means that such a model would fail to account for impacts of energy policies on different sections of the population.

The third modelling approach is due to the works of Harberger (1962), Scarf (1967), and Shoven and Whally (1984). Harberger (1962) used a two sector general equilibrium model of tax and trade cast in the Walrasian and Heckscher-Ohlin traditions. Scarf (1967) on the other hand was the first to offer an algorithm for computing a Walrasian general equilibrium. Later, Shoven and Whalley (1984) implemented the Scarf algorithm to finding a general equilibrium with taxes (Bergman and Henrekson, 2003). The main characteristics of their approach are: (i) multiple households, each with initial endowment and set of preferences, (ii) detailed formulation of tax structures, and (iii) closely follow the Walrasian general equilibrium theory to analyse welfare effects of different policies. The model solution is found by calibration, just like the MSG model (Bhattacharyya, 1996).

Separately, Goulder is one of the most prominent authors applying the Harberger and Scarf models to energy studies (Borgess and Goulder, 1984, Goulder, 1994; Goulder, 1995a, Goulder, 1995b, Goulder et al., 1997; Goulder et al., 1999). Borgess and Goulder (1984) is a disaggregate model of 24 sectors developed for identifying direct, dynamic and terms of trade components of the impact of energy on the long-run growth. In addition, there were 12 household types and as the main feature of the model, production accounted for the possibility of substituting other factors for energy as relative prices changed.

The major criticism against the Harberger, Scarf, and Shoven and Whally (HSSW) type of models is their simplifying assumption of perfect competition and absence of rigidity and uncertainty. However, the HSSW models have become popular because of their intuitive appeal for 'putting numbers on theory'. In addition, the HSSW models are transparent and consistent with basic economic theory, and have proven useful for conducting welfare analyses focused on the efficiency and distributional effects of various economic policy measures (Bergman and Henrekson, 2003).

Many of the general equilibrium energy models could easily be redesigned for analysis of carbon taxation and other types of climate policies (Bergman and Henrekson, 2003). For example, Thompson (2000) analyses the theoretical link between energy taxes, production and income distribution. The study showed that energy taxes cause adjustment in production through two channels: (i) factor intensity, whereby the relative inputs of productive factors change across sectors and (ii) factor substitution, whereby firms switch between productive factors as relative prices change.

Thompson (2000) concluded that energy tax lowers the supply price of energy with the resulting income distribution among factors depending on factor intensity and income. In particular, the conclusion was reached based on two extreme cases: (i) if energy is an extreme factor in the factor intensity ranking, energy tax raises the return to other extreme factor(s) and lowers the return to the middle factor, while (ii) if energy is a middle factor, energy tax lowers the return to every factor. The case of small open economies is particularly interesting for economic growth implications as Thompson (2000) concludes that energy tariff lowers energy imports and has the potential of lowering wages.

Most studies find that environmental taxes typically aggravate pre-existing tax distortions by raising the cost of pollution abatement (Bovenberg and Goulder, 1996; Kim, 2002, Goulder, 1995a; Goulder, 1995b; Boyd and Ibarraran, 2002). In particular, when pollution costs are treated as extra expenditures necessary to produce the same level of valued output, but as income for the environmental regulator, outputs will become more expensive for consumers, hence the economy may experience declining real wages over time. Traditionally, declining real wage may imply declining productivity of labour when it has less capital to work with. Since savings are linked to income, the lower real wages result in less capital formation, and therefore sluggish economic growth (EPA, 1999).

Copeland and Taylor (1999) criticise the standard economic approach to trade and environment for failing to account for feedback effects between pollution and productivity in the economy. The result that environmental compliance is costly is usually driven by the assumption that pollution is harmful only because consumers suffer a disutility cost from pollution. Copeland and Taylor (1999) argue that if pollution also affects productivity, then it can jeopardize long-run sustainability and lower the competitiveness of environmentally sensitive industries. In a related argument, Mestelman (1986) demonstrated that when the negative effects of production are internalised with the use of a Pigouvian corrective tax, the optimal output of the representative firm in the polluting industry will be the same as the *status quo* if the firm's production function is homothetic. Hence, in the presence of other distortionary taxes, environmental regulatory instruments tend to compound those pre-existing distortions, a cost that is recognised as "tax interactions" or "interdependency effects" (Kim, 2002).

In response to the controversy surrounding the handling of feedback effects, Markandya (2001) suggests that the research issue is really one of adopting more sophisticated models to study the incidence effects of policy measures, especially when the policies affect a wide range of industries and result in a number of relative price changes. In such cases, a general equilibrium model is critical to accounting for the feedback effects of pollution even when such feedbacks are limited to the inter-industry dependence alone without considering the economy-environment nexus. In addition, such studies would in most cases conclude that in the presence of other taxes, the second-best optimal pollution tax lies below the Pigouvian level (Bovenberg and Goulder, 1996; Oates, 1995). Also, since pollution is highly correlated with the use of particular inputs (for instance biomass and fossil energy) in the production process, its abatement cost would depend on the substitution possibilities among inputs or other adjustments in production process (Kim, 2002).

Related to the issues raised by Markandya (2001) and Kim (2002) concerning appropriateness of modelling pollution abatement activities, Klepper and Peterson (2006) note that in most general equilibrium studies, abatement activities are ignored because of the gap that exists in scientific representation of, for example, carbon sequestration technologies. However, under certain conditions, and for selected emissions, it is still possible to define marginal abatement cost curves (MACCs) in general equilibrium where abatement level influences energy prices and in turn national MACCs. In their framework, Klepper and Peterson (2006) define marginal abatement cost (MAC) as the shadow cost that is produced by a constraint on carbon dioxide emissions for a given industry (or region) and a given time, or a tax that would have to be levied on emissions to achieve a target level, or a price of an emission permit in the case of emission trading.

There are however problems with political and economic implications of environmental taxes especially in developing countries. In particular, there are concerns that the introduction of an environmental tax would exacerbate existing distortions in the tax system (Bovenberg and Goulder, 1996). In addition, because of thin tax bases the introduction of environmental taxes in developing countries would necessitate revenue reforms aimed at eliminating distortionary taxes on income. In that regard, CGE modellers debate whether environmental taxes should or should not be revenue- neutral (i.e., reducing other tax rates so that the overall tax revenues remain constant). The related issue is whether or not there exists a “double dividend,” i.e., that environmental taxes result in not only a better environmental quality, but also a less distortionary tax system, thereby improving economic welfare.

Addressing environmental concerns in the context of a changing economy may also result in ambiguous projections of impacts. Most developing countries carried out significant structural reforms after the oil price crises of the 1970s and the subsequent debt crises of the late 1980s. Taeh and Holmoy (2003) found that trade reforms may cause a structural change in favour of heavy polluting export industries when exports prices increase over time. Environmental regulation may cause structural shifts due to changes in relative factor prices (costs to firms) and relative prices of output. These changes may lead to perverted environmental scenario, worse than the distortion the policy was meant to correct.

Thus, tax reforms aimed at incorporating environmental concerns would have to consider the efficiency and distribution effects of such reforms. The imposition of a tax on an activity will, in general, reduce welfare of the taxpayer. The issue that arises is how increases in marginal tax rate influence actions of economic agents. Some taxes are particularly distortionary because they impose a burden over and above the revenue that they are supposed to raise. Widmalm (2001) finds that the proportion of tax revenue raised by taxing personal income has a negative correlation with economic growth. As pointed out above, policy makers must contend with the finding in literature that environmental taxes typically aggravate pre-existing tax distortions by raising the cost of pollution abatement (Bovenberg and Goulder, 1996; Kim, 2002).

CGE models have variously been used in search for optimal taxation and in analysing tax reforms in the presence of externalities in a second-best framework (Mayeres and Regemorter, 2003; Bovenberg and Goulder, 1996; Jorgenson and Wilcoxen, 1993). The feedback effects of an environmental tax depend on how the tax affects households and firms. A progressive income tax is often imposed to correct the distortion caused by the initial distribution of wealth, and market power. In a CGE, the total welfare effect of a tax reform may be measured by the change in total utility. For example, Goulder (1994) tested the "double dividend" proposition of an environmental tax, i.e., that environmental tax not only improves the environment but also reduce the non-environmental costs (deadweight loss) of the tax system. The results from the study validated the theoretical insight that taxes on intermediate inputs cause larger welfare costs through distortions in labour and capital markets in addition to the effect on the input. The double dividend is examined from exploitation of existing tax wedges in the labour market and between consumption and saving. The size of the inefficiency costs in the existing taxes determines the prospect for a double dividend when an environmental tax reform is introduced (Bye, 2000).

Van Heerden et al. (2006) used a CGE for South Africa to assess the potential for triple dividend, i.e., reduction in carbon emissions, increase in GDP and reduction in poverty by recycling environmental taxes. The study focuses on energy-related emissions as about 94 percent of South Africa's electricity generation is coal-fired. In a related study, Blignaut et al. (2005) used a national energy balance to compile a greenhouse gas emission database using sector-by-sector consumption figures. The results showed that electricity generation sector contributes almost 51 percent of the emissions. South Africa's carbon emissions are between that of upper-middle income and the high income countries' at 7.4 metric tons per capita. However, South Africa is a non-annex I country according to the Kyoto Protocol on climate change.

In view of previous results that South African energy demand is complementary to capital while energy production is complementary to capital and labour (Blignaut and de Wet, 2001), Van Heerden et al. (2006) concluded that the absence of energy taxes provided an opportunity for exploring a double or even triple dividend. In particular, because of non-existence of energy taxes, a reduction in energy demand through the introduction of energy taxes would not lead to a fall in tax revenue directly. For South Africa however, a triple dividend was achieved when any of the proposed environmental taxes was recycled through reduction in food prices.

The "double dividend" hypothesis is criticized on several counts. First and foremost, environmental taxes have been shown to exacerbate, rather than alleviate pre-existing tax distortions (Bovenberg and Goulder, 1996). Second, the existence of a double dividend should not be taken as a principle, but rather left to empirical investigation. In most studies, the effects of tax and subsidy reforms are evaluated jointly by believing in advance that a double dividend exists. Third, while removing distorting subsidies and taxes may result in environmental and welfare gains, generalizations of the double dividend results are invalid to the extent that countries differ considerably in tax structure and factor markets (Miller et al., 2002).

3.3 Energy as consumer good

The standard neoclassical approach to explaining consumer behaviour can be used to study household demand for energy goods. In particular, consumers may be assumed to choose a fuel or a fuel-mix bundle that maximizes their utility subject to a bounded endowment set. However, energy consumed by households is a function of some underlying demand for a durable good service such a heating, lighting, refrigeration, or powering home equipment. Therefore, household energy demand and demand for energy-using household durable stocks such refrigerators, cookers, and entertainment units are weakly separable (Baker et al., 1989; Bernard et al., 1996).

Household energy demand can also be factored into two components representing efficiency of some type of energy-using capital equipment and the level of utilization of that equipment (Cameron, 1985; Biesiot and Norman, 1999). In general, a household's utility over energy and non-energy goods can thus be expressed as:

$$V = V\left[U(E), c\right] \qquad (3.12)$$

Where E is a vector of energy goods, and c is a vector of all consumption goods, excluding energy-using stocks.

Utility is maximized subject to a budget constraint defined by household endowment of resources including labour, land and property. Baker et al. (1989) consider households that first allocate resources between energy and non-energy products, and then decide how to divide the total energy outlay among different fuels. Modern fuels such as electricity, kerosene and petroleum fuels have associated fixed costs (e.g., connection cost of electricity) and consumption-dependent charges. Biomass fuels collected or produced by the household itself carry the opportunity cost of time spent collecting fuelwood, or the opportunity cost of dung converted to energy that could have been used as manure to replenish soil nutrients (Heltberg et al., 2000; Heltberg, 2005). Households that obtain fuel from markets face market energy prices as a decision parameter, while those that collect or produce own biomass face a reservation price for biomass as determined by biomass availability and the opportunity cost of collection labour (Heltberg et al., 2000).

3.4 Approaches to studying household energy substitution

Various approaches have been used to study the substitution between different energy sources at household level. The most prominent approaches are the household production framework in which demand for fuel is a function of an underlying demand for services from household durables that use energy and the random utility framework in which fuel choices at household level are modelled using a multinomial logit model.

3.4.1 Household production framework

Household production satisfies basic services such as provision of food, shelter and clothing. Some of these services are produced using market goods (inputs) while others are produced using own labour and open access resources. In most cases the products of household production are tradable in nature although they are neither sold nor bought by members of the household. Households maximize utility by allocating optimal amounts of labour to different home production tasks and by purchasing market goods (inputs) subject to a broadly defined income constraint that includes own labour and endowments (Bandyopadhyay et al., 2006).

In the context of a developed country, Baker et al. (1989) specified consumer demand for fuels within a household production framework where the underlying demands are for services from energy-using capital equipment. In their model, Baker et al., allow the marginal rate of substitution across disaggregated energy demands to differ across households with different durable stocks, hence making energy demand non-separable from the stocks. In a related study, Vaage (2000) describes energy demand as a combination of discrete and continuous choice problems. In the first instance, household appliance choice is specified as a multinomial logit model with a mixture of appliance attributes and household's own characteristics. Then energy use is modelled conditional on the appliance choice. Thus, energy use depends on utilization of a given stock of energy-using appliances just like in Cameron (1985) and Biesiot and Norman (1999).

Boonekamp (2007) used a simulation model to analyse the relationship between historic energy prices, policy measures and household energy consumption. Household energy consumption was divided into seven energy functions: space heating, supply of hot water, cleansing (e.g. washing machines), cooling, cooking, lighting and other appliances. Like in Baker et al. (1989), demand for each energy function is met by one or more energy consuming systems or appliances, and for every system or appliance, total energy consumption is defined by three factors: ownership, intensity of use and efficiency of the system or appliance.

Although the household production framework is theoretically sound and quite useful in developed countries and other applications, the model has limited use for analysing energy demand in developing countries. In particular, most households' energy choices in developing countries have radically different structures than those presented by Baker et al. (1989), Vaage (2000), and Boonekamp (2007). In particular, because of widespread poverty, ownership of energy-using capital stock or appliances is low and hence would not explain much of households' energy demand. For instance, Vaage (2000) found that high income households tend to choose electricity as the only heating energy source while solid fuels such as fuelwood were unpopular. Thus, using these studies, one would conclude that low income households use fuelwood either because of lack of energy-using capital stock or because of low income.

Heltberg et al. (2000) also used a household energy production framework to estimate demand for fuelwood in rural India. The focus of the study, however, was on the substitution between non-commercial fuels a household obtains from open access sources (commons) and fuels obtained from the energy market. Elasticities were obtained from maximum entropy regression estimates of fuelwood collection, collection labour time and private energy consumption. The major result was that households respond to fuelwood scarcity and increased fuelwood collection time by substituting commercial fuels for forest fuelwood. However, the substitution rate was deemed too low to prevent current fuelwood collection from causing serious forest degradation. The other weakness of the model was that it was practically impossible to endogenize factors driving household choices between fuelwood from open access sources and commercial fuels in fulfilling a particular household function.

In a study of Zimbabwean households, Campbell et al. (2003) used two surveys of fuel use by low income households to describe energy transition from wood to electricity by means of a series of chi-square tests. Although the methodology is not similar to the household production framework, the underlying hypothesis is very close to assuming that households demand energy as a result of ownership of appliances. In Campbell et al. (2003) households were faced with an array of energy choices arranged in order of increasing technological sophistication. Using such an ordering, also called an "energy ladder", households were hypothesized to make the transition from biomass fuels through kerosene to Liquid Petroleum Gas (LPG) and electricity, with the corresponding reduction of pressure on woody plant resources that form the bulk of biomass energy sources.

Campbell et al. (2003) accepted the energy ladder hypothesis, with income as the main determinant. About 3 percent of households switched to electricity from other fuels, citing as their main reasons the acquisition of a new appliance that required electricity and moving to new premises. However, other households did not use electricity because of lack of access (5percent) while the majority (51percent) of the households cited price as a deterrent. The use of wood for cooking ranged from 1.5 tons/year per household in 1994 to 0.7 tons/year in 1999. The study also concluded that most households use mixtures of fuels but failed to prove that the fuel stack varied over time. Fuel security was offered as an explanation to fuel stacking behaviour in response to insufficient or unreliable electricity supply. In addition, the proportions of fuels in household energy budgets were driven by price considerations for not only the fuels but also complementary appliances.

There are a number of challenges to the "energy ladder" hypothesis. First, widespread poverty in developing countries may lead to the conclusion that the energy ladder is nonexistent because proportionately large number of households are perpetually unable to afford other sources of energy apart from collecting biomass from open access sources and own fields. Second, households tend to use more than one fuel at a time, thus the transition process is not from exclusive use of one fuel to exclusive use of another, but from one fuel combination to another (Hosier and Dowd, 1987). Thus, the "energy ladder" hypothesis ought to be phrased in terms of proportion of biomass fuels in household energy compared with electricity over time. Also, there is need to identify the determinants of household fuel preferences and why households use one fuel or multiple fuels to fulfil a single household function.

3.4.2 Random utility framework and multiple fuels

The functional form of the utility from energy goods aggregate $U(E)$ in equation 3.12 may be specified as follows. Let U_{hj} be the indirect utility a household h obtains from acquiring fuel j. For a given set of K-energy sources (or just fuels), a typical household would consume zero or more fuels depending on the fuels' unique attributes which include the total economic cost of obtaining the fuel. Since some households obtain fuels from open sources, the total economic cost of energy consumed by a typical household is unobservable, but can be estimated from a random utility framework based on an indirect utility of the form:

$$U_{hj} = U\left(F_j^H, \xi_j, e, \tau_j; \theta\right) = \alpha_h y_h + F_j^H \beta - e_j \alpha + \xi_j + \mu_{hj}\left(F_j^H, e, \tau_j; \theta_2\right) \qquad (3.13)$$

Where α_h is household $h's$ marginal utility from income, F_j^H and ξ_j are observed and unobserved fuel characteristics, respectively, e is a vector of energy prices, τ_j is a vector of household characteristics influencing preferences over fuel j, and $\theta = (\theta_1, \theta_2)$ is a vector of unknown parameters. The last term $\mu_{hj}(\cdot)$ represents zero mean but heteroskedastic error term.

Following Nevo (2000), if the error term $\mu_{hj}(\cdot)$ is independently and identically distributed (i.i.d.) following a Type I extreme value distribution, equation 3.13 reduces to a standard logit model where the share of fuel j in household aggregate energy expenditure is:

$$s_j = \frac{\exp\left(F_j\beta - e_j\alpha + \xi_j\right)}{1 + \sum_{j=1}^{K}\exp\left(F_j\beta - e_j\alpha + \xi_j\right)} \tag{3.14}$$

Ouedraogo (2006) used a multinomial logit model to analyse factors determining household energy choices in urban Ouagadougou. The data and empirical analysis show that the actual (predicted) probability of a household adopting fuelwood as main cooking energy is 79.1 percent(92.2percent), and for kerosene is 2.7 percent(0.0percent). Household income was not significant for explaining demand for firewood probably because firewood users were the poorest households in Ouagadougou. It was also found that high costs of modern cooking energy and their capital stock requirements like cooking stoves are constraints for household fuel preferences.

Heltberg (2005) used the 2000 Guatemalan household survey to analyse patterns of fuel use, energy spending, Engel curves, multiple fuels (fuel stacking) and the extent of fuel switching. A significant share of fuelwood users were incurring more costs acquiring fuelwood from markets compared with the costs of modern fuels. The evidence also suggests that the widespread collection of firewood in rural areas is due to the low opportunity cost of labour time. Thus, rising labour cost may be the only factor capable of effectively regulating firewood supply from open access forests and commons.

Heltberg (2005) also estimated Engel curve regressions for LPG and firewood. It was found that prices were important for interfuel substitution although many households were using multiple fuels (fuel stacking) for cooking. Thus, for low income countries, fuel switching policies should be guided by determinants of not only fuel substitution but also factors that drive fuel complementarities. By employing a multinomial logit analysis of all possible fuel choices, Heltberg (2005) finds that education is a strong determinant of fuel switching from fuelwood to LPG while having electricity is associated with fuel switching by inter alia, being associated with smaller probability of using only wood, or only LPG.

The problem with the multinomial logit model used by Heltberg (2005) is that it excludes from the estimation households that collect firewood (sample selection bias), yet the opportunity cost of labour collection time is an important determinant of fuel substitution/complementarities for rural households. Econometrically, the main weakness of the multinomial logit model is the i.i.d. assumption. The assumption implies that the cross-price elasticities of demand do not depend on observed fuel differences (Besanko et al., 1989) and that own-price elasticities are proportional to own price (Nevo, 2000).

As a solution, Besanko et al. (1989) suggest using the generalized extreme value (GEV) or nested logit structure. The idea of nesting is to induce correlation among fuel options by grouping all fuels used by households into predetermined exhaustive and mutually exclusive sets (Nevo, 2000). The other solution is to use a segment specific dummy variable as one of the characteristics of the fuels under consideration. According to Nevo (2000), this is equivalent to estimating the multinomial system with the group specific dummy variable acting as one of the characteristics of the fuels.

3.5 Chapter summary

This chapter reviewed the literature on approaches to studying energy demand and fuel switching policies. The chapter also discussed both the perspective of energy as a factor input in production and as a consumer good that enters household utility functions either directly or indirectly.

For energy as an input in production, the reviewed studies can be categorized into two main groups: (i) those that focus on factor intensities and (ii) those that focus on energy switching, or factor substitution. In the first category, there are descriptive nonparametric approaches for which DEA is the main tool of analysis and parametric partial equilibrium (energy sector) approaches for which regression analysis is used. For the second category, both regression based approaches and AGE with or without regression estimates of substitution elasticities have been reviewed.

For sectoral energy intensities and related questions of energy efficiency, the DEA offers invaluable insights that could be used to foster energy efficiency as an environmental policy objective. However, the review has shown that technical progress is exogenous to the DEA system, hence limiting its use in energy switching studies. Similarly, for AGE models, the chapter has indicated that the focus of many energy studies is now shifting to examining the impact of emission reduction on energy prices following the Kyoto Protocol. Most of the literature on AGE impacts of Kyoto Protocol, such as the reduction in carbon dioxide emissions, is developing on the premise that meeting emission targets is the only policy objective that could be followed, although others, for example Otto et al (2006) and Smulders and de Nooij (2003) have tried to endogenize technical progress.

The literature review has therefore shown that energy intensity and factor substitution are important for the efficacy of energy policy. However the literature offers no consensus on the appropriate technological specification for substitution possibilities between energy and non-energy factor inputs. Similarly, the literature does not offer much agreement on the appropriate delineation of energy biased technical progress. From the foregoing, and considering objectives of this study, there is need to integrate approaches that focus on factor intensities and substitution possibilities on one hand, and those that seek to meet environmental targets.

For household energy demand, the literature from developed countries seem to advocate the household framework since household energy demand in those countries is intricately related to ownership and utilization of energy-using appliances. The review highlighted the inappropriateness of the household production framework similar to that of Baker et al. (1989) in studying household energy demand in developing countries where the majority of the households are rural based and poor. The random utility framework came out as a viable approach for analysing household fuel choices and for identifying and quantifying factors that determine the choice of one set of fuels from another in fulfilling a household function.

CHAPTER 4: STUDY APPROACH

4.1 Introduction

In this chapter, the model for estimating interfuel substitution and energy aggregation is specified. This is followed by specification of the CGE model used to assess the implications of shifting the energy mix of the Malawi economy from biomass and fossil fuels to hydroelectricity. In an economy like Malawi where carbon-intensive fuels make up 39 percent of energy used by production activities and fuelwood accounts for over 20 percent of energy use in some sectors (NSO, 2001), taxes on carbon emission and on fuelwood use are expected to raise energy prices causing a fall in demand for energy by production activities. Hence, the CGE model is specified to assess the distributional effects of an environmental policy regime that taxes fuelwood and high carbon fuels and subsidizes alternative low carbon substitutes.

The rest of the chapter is organized as follows. Section 4.2 presents the model for estimating substitution elasticities among fuels in the energy aggregate and between energy and non-energy aggregate inputs. Section 4.3 presents the empirical framework for analysing energy-economy interactions. Section 4.4 summaries the chapter.

4.2 Modelling interfuel substitution and aggregate energy and non-energy input substitution

Following the work of Fuss (1977) this study adopts the assumption of homothetic weak separability between energy and other inputs (labour and capital) in production, which allows writing of the firms' technology constraint as:

$$Y = f\left(K, L, E\left(E_i\right)\right) \tag{4.1}$$

Where Y is output, K and L refer to capital and labour, respectively and E is the aggregator function of the energy sub-model. Duality theory implies that the corresponding cost function (C) under cost minimization will also be weakly separable:

$$C = G\left(P_E\left(P_{E_i}\right), P_K, P_L, Y\right) \tag{4.2}$$

P_E is the energy price aggregator index and P_{E_i}, P_K and P_L refer to prices of individual energy components, capital and labour inputs, respectively. Under the assumption of homothetic separability one can apply the two-stage aggregation model which assumes that firms first decide their optimal fuel-mix before considering quantities of non-energy inputs. Once the energy aggregate is composed, firms then vary their optimal energy aggregate in response to changes in demand for non-energy factor inputs (Mountain and Hsiao, 1989; Kemfert and Welsch, 2000; Klepper and Peterson, 2006). Applying Shephard's lemma (Diewert, 1971) we derive from equation 4.2 the system of cost-minimizing input demands $Z_i = \left[\partial C / \partial P_i\right]$.

This study uses the unrestricted quadratic quasi Cobb-Douglas system of equations based on relative fuel demands in the energy aggregate. This is a parsimonious system that extends the multi-input log-ratio formulations of the translog and linear logit models and is consistent with Pindyck's (1979) two-stage aggregation model. Others have used Pindyck's assumption to minimize the number of estimated parameters (Mountain and Hsiao, 1989). Once the energy aggregate is composed, firms then vary their optimal energy aggregate in response to changes in demand for other factor inputs. Thus, the energy demand system is estimated on the assumption of homotheticity and separability of energy from other inputs (Mountain and Hsiao, 1989; Kemfert and Welsch, 2000; Klepper and Peterson, 2006).

The main energy sources used by firms in Malawi are hydroelectricity, oil, fuelwood and coal. Ignoring sector specific identifiers and time subscripts, the unrestricted quadratic log-ratio demand system for four fuels is specified as:

$$\ln\left(\frac{X_i}{X_1}\right) = \ln\left[\frac{\left(\partial C/\partial p_i\right)}{\left(\partial C/\partial p_1\right)}\right] =$$

$$\alpha_i + \sum_{j=2}^{4} \alpha_{ij} \ln\left(\frac{p_i}{p_1}\right) + \frac{1}{2}\sum_{j=2}^{4}\sum_{m=2}^{4} \alpha_{ijm} \ln\left(\frac{p_j}{p_1}\right) \ln\left(\frac{p_m}{p_1}\right) + \beta_i^X d_i^X + \iota(t) + \varepsilon_i \tag{4.3}$$

Where $X_i, i = 2,3,4,$ is fuel $i's$ demand in real quantities, p_i is the corresponding unit price, α, β and ι are unknown parameters, t is time trend variable and ε_i is a white-noise error term. To account for differences in energy mix technologies in estimating equation (4.3), a set of dummy variables are defined in order to incorporate all observations for which the variables $\ln\left(\frac{X_i}{X_1}\right)$ and $\ln\left(\frac{p_j}{p_1}\right)$ are undefined or zero. This method was suggested by Battese (1997) and has been applied in energy studies (Brannlund and Lundgren, 2004). In particular, let:

$$d_i^X = \begin{cases} 1 \quad if \quad \ln\left(\dfrac{X_i}{X_1}\right) \text{is undefined} \Rightarrow \text{set} \ln\left(\dfrac{X_i}{X_1}\right) = 0 \\ 0 \, \text{otherwise} \end{cases} \tag{4.4}$$

According to Considine and Mount (1984), most producers would base their input demands on expected prices of inputs. Accordingly, the aggregate input demand function would be more realistic by incorporating price expectations that proxy adjustment costs over time. Also, since there are asymmetric responses among firms to energy price changes, an econometric specification that includes a lagged dependent variable approximates firm specific adjustment cost to input price changes. The dynamic adjustment term that must be added to equation 4.3 is defined as:

$$\lambda_i \ln\left(\frac{X_i}{X_1}\right)_{t-1} \tag{4.5}$$

Where λ_i is a coefficient for the lagged value of the dependent variable.

The hypothesis that the rate of dynamic adjustment influences energy use intensities and vice-versa could not provide meaningful policy insights if tested on a relative demand system of fuel inputs only (Jones, 1996; Brannlund and Lundgren, 2004). Instead, a relative demand system that includes the energy aggregate, labour and capital is preferred with the view to accounting for cross-elasticities of substitution between energy and labour and between energy and capital, in addition to accounting for dynamic adjustments. Since technological change could also be influenced by the rate of dynamic adjustment, an interactive term for share neutral technological change is included in the specification of factor demands. Accordingly, the relative factor demand system under the assumption of non-neutral technical progress with dynamic costs is specified as:

$$\ln\left(\frac{Z_i}{Z_n}\right)=\beta_i+\sum_j\beta_j\ln\left(\frac{w_i}{w_n}\right)+\frac{1}{2}\sum_j\sum_m\beta_{ijm}\ln\left(\frac{w_j}{w_n}\right)\ln\left(\frac{w_m}{w_n}\right)+\beta_t t+\beta_y\ln Y+\lambda\ln\left(\frac{Z_i}{Z_n}\right)_{t-1}+\mu_t \tag{4.6}$$

For i, j, m referring to (K, L, E) and $\beta_{ijm}=\beta_{imj}$ while Z_n is quantity of a quasi-fixed input chosen from among capital (*K*), labour (*L*) and energy aggregate (*E*) and $w's$ are input prices.

In most time series studies, price elasticities vary according to sector suggesting that sectoral size or energy intensity differences may have a role in determining elasticities. Price and production elasticities may also vary between sectors due to differences in production technology across sectors (Mountain and Hsiao, 1989). For these reasons, it seems natural that the appropriate approach to estimating energy demand elasticities is micropanel econometric techniques. Micropanel models allow for heterogeneity between sectors unlike aggregate macro data or micro cross-section data models (Bjørner et al., 2001).

The assumption made about the error term of equations 4.3 and 4.6 would in most cases determine the estimation method. Generalized least squares (GLS) and seemingly unrelated regression (SUR) methods provide consistent and efficient estimates when equations are contemporaneously correlated through the error terms. While GLS parameter estimates depend on the choice of base variable or the equation dropped to achieve a non-singular equation system, maximum likelihood (ML) estimates are invariant to arbitrarily choice of base variable (Frondel, 2004; Urga and Walters, 2003). Also, since the iterative Zellner estimator for SUR is equivalent to ML and is invariant to the choice of transformation used to define the base (Considine and Mount, 1984), ML is the preferred method for estimating both the interfuel demand system and system of aggregate energy and non-energy inputs. ML is also appropriate if the covariance matrix and parameters are changed after every iteration regardless of whether errors are independently and identically distributed.

In this study, only capital is considered quasi-fixed over the relevant time frame in estimating equation 4.6. This allows the estimation of the dynamic adjustment rate, λ as labour and energy inputs vary. Also, the equation system 4.6 is estimated using GLS assuming uncorrelated but autoregressive structure of the residuals within panels. Econometrically, price response dynamics may be interpreted as an approximation for first differences which is a method for eliminating activity or firm specific effects. Mountain and Hsiao (1989) interpreted this specification as an error-correction mechanism denoting the target equilibrium factor demand ratio that is derived from Shepherd's lemma.

The unrestricted quadratic log-ratio specification has other appealing properties. First, the system does not suffer from the same econometric problems that plague the linear logit model. Second, the resultant demand system can be derived from some underlying cost function satisfying regularity conditions (Mountain, 1989; Mountain and Hsiao, 1989; Considine, 1990). Third, for energy and natural resource inputs that are usually a small proportion of total production cost, realistic elasticities of substitution can be estimated without compromising structure and parsimony of the estimated system.

The specification of factor demands in equations 4.3 and 4.6 has conceptual similarities to the cost shares model used by Jones (1996), and Brannlund and Lundgren (2004). First, both systems are theoretically consistent as they are derived from Shephard's lemma. Second, both systems can be used to estimate elasticities of substitution that are based on viable cost functions, in the sense that the underlying functions satisfy homogeneity, monotonicity, symmetry, and concavity conditions (Mountain and Hsiao, 1989). Whereas the cost shares system from linear logit model is closer to translog specification, the relative factor demand system in log form is closer to CES formulations and to generalized Leontief forms when relative factors are in levels (Mountain and Hsiao, 1989). Since the unrestricted quasi Cobb-Douglas demand system in equation 4.1 satisfies homogeneity assumption (Mountain and Hsiao, 1989), the system can be rewritten as:

$$\ln\left(\frac{X_i}{X_1}\right)=\left\{\frac{[\partial C/\partial p_i]}{[\partial C/\partial p_1]}\right\} \tag{4.7}$$

Where C is a homothetic cost function from which equation 4.3 is derived (Mountain, 1989).

Also since the unrestricted quasi Cobb-Douglas function is a finite order function of the logarithms of factor input prices (Hsiao and Mountain, 1989), the Morishima substitution elasticity exists and is defined as:

$$MES_{ij} = -\frac{\partial \ln\left(X_i / X_j\right)}{\partial \ln\left(p_i / p_j\right)} = -\partial \ln\left\{\frac{\left[\partial C / \partial p_i\right]}{\left[\partial C / \partial p_1\right]}\right\} \Big/ \partial \ln\left(p_i / p_j\right) \tag{4.8}$$

The subsidy and tax policy would, through own-price and cross-price elasticities, have impacts on energy and non-energy input demands that could alter output and welfare outcomes in the economy. Thus, equations 4.3 to 4.6 can only give answers concerning substitutability among fuels and between energy and non-energy aggregates such as labour, and capital, in addition to offering insights on dynamic elements giving rise to structural changes in aggregate input demands over time. Also, the linearly homogenous forms makes these functions suitable for analysing factor price responses from the corresponding dual production function (Färe and Mitchel, 1989). However, considering that policy induced changes in energy supply may have profound effects throughout the economy, a general equilibrium framework is the appropriate method for analysing the impact of policy restriction on demand for biomass fuel and on carbon emission from fossil fuels.

4.3 The general equilibrium framework for analysing impacts of energy policies

To analyse the interdependence between the economy and the environment, there is need for explicit functional specifications of the links between the economy, measured in monetary terms, and the physical levels of environmental flows (Leontief, 1970; Mestelman, 1986). Materials extracted from the environment must ultimately either be embodied in durable assets or returned to the environment as wastes or pollutants (Ayres, 2001). In this study, the economy's interaction with the environment consists of a set of energy, material resources and pollutants per monetary unit of final output of commodities produced (Kratena, 2004; Ferng, 2002).

Letting D be a $1 \times N$ vector of sectoral environmental input use i.e., biomass and fossil fuels, A be a direct requirement matrix and I be an identity matrix, the factor multipliers representing an embodiment of energy, material resources and pollutants per monetary unit of final output are given as:

$$M^{*E} = D(I - A)^{-1} \tag{4.9}$$

Taking final demand, Q^D as the amount of industry output consumed by final consumers and AQ as the total output consumed by domestic production processes, the following equilibrium condition must hold:

$$Q^D = Q - AQ \tag{4.10}$$

If Q^D is exogenous, and the input structure does not change when industry changes scale, the model can be solved for final output Q:

$$Q = (I - A)^{-1} Q^D \tag{4.11}$$

Similarly, any given level of final output and vector of environmental inputs, Z^E (biomass and fossil fuel in this case), there is a corresponding level of carbon emissions:

$$D_C^E = Z^E (I - A)^{-1} Q \tag{4.12}$$

Equations 4.9 to 4.12 are adequate for input-output analysis of the environmental problem at hand. However, modelling the integrated aspects of environment and economy linkages requires functional specification of the behaviour of main drivers of change. Since production activities are the main energy users, a tax on emissions simultaneously implemented with targeted tax and subsidy policies on some fuels will alter not only profit conditions of concerned firms but also the distribution of gains and losses in the economy.

The objective function for a sector that faces environmental taxes is expressed as one of maximizing profit subject to technology and environmental constraints:

$$\pi(p,q) = p \times f\left(z, z_{ij}^{E}\right) - g\left(w, p^{E}\tau', q\right) \tag{4.13}$$

Where $f\left(z, z_{ij}^{E}\right) = q$ is a production function with regular first and second partial derivatives, $z = (K, L, S, IND)$ is a vector of inputs namely capital (K), labour (L), land (S), and non-energy intermediate inputs (IND), z_{ij}^{E} are energy intermediate inputs and $g\left(w, p^{E}, q\right)$ is a cost function with dual analogy to the production function, and $w = \left(p_{K,} p_{L}, p_{S}, p_{ji}\right)$ is a vector of prices corresponding to the inputs in vector z. Similarly p^{E} is a vector of prices corresponding to energy intermediate inputs in the vector $z_{ij}^{E} = (Fuelwood, Coal, Oil, Hydroelectricity)$ and τ' is a column vector of taxes or subsidies levied on biomass fuel and carbon emissions embodied in the energy inputs, respectively.

A profit maximizing sector would demand energy and non-energy inputs depending on the level of output, price of final output, unit cost of inputs as well as taxes imposed on carbon emissions and biomass fuel use. Thus production sectors choose inputs according to the following set of first order conditions:

$$\frac{\partial \pi(\cdot)}{\partial z} = p \cdot f'\left(z, z_{ij}^{E}\right) - g'\left(w, p^{E}\tau', q\right) = 0 \tag{4.14}$$

Re-arranging equation 4.14 provides an implicit rule for selecting inputs in the presence of environmental constraints. In particular, environmental taxes reduce the net value of output by the corresponding unit environmental taxes on output. Hence, the rule states that at optimum, a sector would be maximizing profit if it equates the net value of marginal product of an input to its marginal cost:

$$p \cdot f'\left(z, z_{ij}^{E}\right) = g'\left(w, p^{E}\tau', q\right) \tag{4.15}$$

The implication of equation 4.15 is that sectors that use highly taxed energy sources are expected to have large reductions in output, and if such sectors contribute a large share to total output of the economy, economic welfare may also decline substantially. However, when fossil fuels and fuelwood are substitutes for hydroelectricity, some of the output and welfare losses may be offset by subsidizing hydroelectricity.

Given the energy profile of the Malawi economy, hydropower use per unit of output is a key determinant of the rate at which firms adjust demand for other fuels in the presence of environmental policy constraints. Specifically, firms have the choice of using hydroelectricity as an alternative source of energy that does not put pressure on forests or increase the economy's greenhouse inventory. With appropriate targets for increasing hydropower demand to offset reductions in fossil and biomass fuels, a subsidy on hydroelectricity would enter equations 4.13- 4.15 as a negative tax when intermediate demand for hydroelectricity is positive to account for the mitigating effect of increasing hydropower on net output loss.

Environmental tax and subsidy combinations are required since the market economy cannot on its own decide the optimal values for biomass and carbon emissions. The problem for the planner is therefore to define socially acceptable levels of biomass extraction and carbon emissions. Accordingly, the vector of taxes in equation 4.15 is associated with constraints imposed on the relevant environmental externality. With duality, the optimal tax and subsidy combination can be established by varying the environmental constraints. The tax and subsidy and the associated environmental constraints trace out marginal cost curves for reducing an environmental externality. The general equilibrium impacts of environmental tax and subsidy policy combination depend to a large extent on the initial fuel shares in the energy input (Klepper and Peterson, 2006).

Sectors that are carbon intensive or biomass fuel intensive face high costs of adjustment to environmental taxes on carbon and biomass. The adjustment costs, often measured in terms of reduction in output, may escalate if there are limited substitution possibilities among energy inputs, and between energy and non-energy inputs. As demand shifts from high to low cost energy inputs, producers may increase or decrease demand for other factor inputs depending on complementarity or substitution possibilities between energy and non-energy inputs. These changes could raise or reduce prices of not only factors of production but also of goods and services, thereby affecting household consumption, government expenditure, savings, investment and economic growth.

In developing countries however, the combined problem of biomass loss in forests and increasing emissions due to energy use pose policy dilemmas. On one hand, emissions per unit of output from developing countries are generally increasing and are proportional to not only fossil fuel use but also deforestation rates in some countries. Thus, reducing emissions now may translate to substantial environmental gains since for every ton of carbon abated from fuelwood combustion at least two tons of fuelwood biomass could be conserved in standing forests (Girard, 2005). In addition, some carbon-intensive fuels like coal and oil can be replaced with capital intensive but energy saving technologies. In addition, environmental taxes aimed at curtailing emissions may stifle development either by reducing output directly as producer prices fall or indirectly through income and consumption effects on households. According to Jorgenson et al. (1992) the analysis of taxes to reduce emissions must consider not only efficiency losses but also effects on equity in the distribution of welfare among households since a tax affects relative prices faced by consumers.

The distributional impacts of biomass and carbon taxes on the economy would also depend on government's option of spending the additional tax revenues. Most studies conclude that the aggregate environmental compliance costs may reduce economic growth because of the existence of other distortionary taxes (Goulder, 1995a; Boyd et al., 1995). Hence, an increase in the price of energy resulting from the imposition of a carbon tax, would disproportionately affect households with large share of energy in total expenditure. For production activities, the impact of a tax on energy inputs would depend not only on the initial input shares but also the substitution possibilities between energy and non-energy factors of production. To reduce negative impacts of additional tax revenue on the economy, most studies propose revenue-neutral environmental taxes, i.e., taxes whose revenue are used to reduce other distortionary taxes so that the overall tax revenue remain constant (Goulder, 1995a; Bovenberg and Goulder, 1996; Goulder et al., 1997; Goulder et al., 1999; Bye, 2000).

In most cases, reducing or eliminating pre-existing inefficiencies may be the only necessary condition for environmental taxes to successfully correct an externality without affecting economic growth and household welfare (Kumbaroglu, 2003; Bovenberg and Goulder, 1997; Böhringer, 1997). When the additional revenue is added to the pool of government revenue, it may be saved or used for current government consumption. The environmental taxes are therefore not revenue-neutral and could potentially aggravate pre-existing tax distortions by raising the cost of pollution abatement (Bovenberg and Goulder, 1996; Kim, 2002). If the government uses the revenue to reduce household direct tax obligations proportional to the initial share of direct tax payments while keeping net government revenues from environmental taxes zero, the system is said to be revenue-neutral.

Equations 4.9 to 4.15 extend the standard CGE model for Malawi developed by Lofgren (2001). Lofgren (2001) explored the effects of external shocks and domestic policy changes aimed at poverty alleviation using a static CGE model calibrated against a disaggregated 1998 social accounting matrix (SAM) for Malawi. However, unlike Lofgen (2001), production in sector i is assumed to be constant returns to scale Cobb-Douglas technology that transforms intermediate inputs including fuels and value added aggregates.

$$Q_i = A_i K_i^{\alpha_{Ki}} L_i^{\alpha_{Li}} S_i^{\alpha_{Si}} E_{im}^{\alpha_{Emi}} ID_{ij}^{\alpha_{ij}}; \quad \sum_{(K,L,S,E,ID)} \alpha = 1 \tag{4.16}$$

Where K, L, S and ID_{ij} are capital, labour, land, and non-energy intermediate inputs, respectively, while E_{im} is energy intermediate of type $m = (\text{coal, fuelwood, oil, hydropower})$. The parameters A_i and $\alpha(*)$ are total factor productivity and Cobb-Douglas elasticities, respectively.

Meeting energy demand by production activities involves distribution of carbon-intensive fuels such as oil and coal and biomass extracted from forests for fuelwood. For accounting purposes, energy producing sectors' transactions with other economic activities are expressed in British thermal units (Btu) to provide a link between partial equilibrium estimates of interfuel substitution at industrial level with the inter-industry transaction represented by the general equilibrium model (Hoffman and Jorgenson, 1977).

In estimating externalities associated with energy inputs, we assume that environmental issues are at the lowest level a function of energy inputs which in turn are determined by the output level. This is consistent with Jorgenson et al. (1992) who assumed that carbon emissions are proportional to energy inputs (fuels). However, we go further and assume that since emissions are generated in production processes, environmental issues have a small positive elasticity of substitution with output. This formulation is consistent with Mizobuchi and Kakamu (2007) who based their functional form on the hypothesis of existence of an environmental Kuznets curve. Environmental issues therefore take the form:

$$E_j^{V^E} = \lambda_j^{V^E} f\left(z, z_{ji}^E\right)^{\sigma_j^{V^E}} \tag{4.17}$$

Where $E_j^{V^E}$ is for production sector j a specific environmental issue, V^E including carbon emissions, biomass extraction and hydro-energy consumption in physical units, $\lambda_j^{V^E}$ is a scale coefficient for environmental issue, $f\left(z, z_{ji}^E\right)$ is production function and $\sigma^{V_j^E}$ is elasticity of environmental issue with respect to output of the sector.

A complete specification of the general equilibrium model would include equilibrium conditions for factor markets, as well as market clearing conditions for energy and carbon emissions. Thus, assumptions must be made about behaviour of households (owners of factors of production) and government (environmental regulator). In particular, saving and investment behaviour must be specified for domestic institutions including regular income generation and expenditure outlays. In addition, the general equilibrium model would not be complete without assumptions about the economy's interaction with the rest of world. A summary of assumptions made about the different actors and markets are given below while the algebraic specification of the general equilibrium model is included in the appendix.

In general, it is assumed that all actors in the economy maximize their respective objective functions. Households are assumed to solve a standard household utility maximization problem involving choosing a consumption bundle that yields the highest possible utility to the household subject to its budget constraint. Household expenditure on consumption is bounded by income that in turn depends on the household's limited endowment of primary factors (labour, capital and land), and exogenous income. In Lofgren (2001), factor incomes generated in the production process are paid in fixed shares to enterprises (owners of capital and land) and to households (owners of labour). In this study, households own all factors of production and that factor incomes are paid directly to households. The allocation of enterprise income to taxes, savings and the rest of the world are likewise interpreted as outlays made by the households themselves. Households also allocate their income to savings, direct taxes and transfers to the rest of the world.

Government receives income from indirect and direct taxes, import taxes and direct transfers from abroad. It is also assumed that government consumes final products in fixed proportions, and that government saves and distributes income to households as direct transfers. The distribution formula applied by this study is regressive in the sense that households with high tax obligations get lower relief than their counterparts. Households receiving a tax relief may save or consume the windfall income in the current period. Unlike Lofgren (2001), government savings are not treated as the residual of the difference between government current revenue and expenditures. Instead, it is assumed that government has an exogenous marginal propensity to save out of its current revenue. It is further assumed that government overall budget deficit is offset by foreign direct transfers to government.

The rest of the world contributes to national savings and because of the small open economy character, it is assumed that Malawi faces exogenously determined international trade volumes and prices. Unlike Lofgren (2001), all domestic demands for imported goods and services by households, government, and for investment and intermediate use are indistinguishable from domestic supply of the same commodity since imports and domestic goods are considered perfect substitutes. However, the quantity of imports and domestic output that makes up composite supply of a commodity is determined by the relative prices of imports and domestic output. Similarly, it is assumed that there is perfect transformability between domestic output that is exported and sold domestically, and export-domestic sales ratios are influenced by relative prices.

The general equilibrium model requires that all markets be in equilibrium. Factors markets are in equilibrium when the total quantity demanded and the total quantity supplied for each factor are equal. Similarly, commodity markets are in equilibrium when the sum of intermediate use, household consumption, government consumption, fixed investment, stock change and trade import use are equal to the aggregate supply of commodities in the economy (Lofgren et al., 2000). In addition, each institution equates its income to expenditures while balance of payments equilibrium is achieved when the sum of import spending and transfers to the rest of the world equal the sum of exports revenue, institutional transfers from the rest of the world and foreign savings. Finally, investment demand equals the supply of loanable funds (savings) in the economy.

4.4 Summary of empirical approach

The chapter has specified in detail the empirical models employed in the next two chapters. The interfuel substitution and aggregate input demand systems are sector specific microeconometric models specifically intended to estimate short-run and long-run elasticities and dynamic adjustment costs for the energy sector. Policy simulations conducted using the microeconometric analysis will reinforce or refute the prospect that energy sector changes could have wider economic implications whose overall cost or benefit can be assessed using an economywide model.

One of the hypotheses to be tested by the microeconomic analysis is that capital, labour and energy input aggregates are substitutes for each other. Hence, the microeconometric model would reveal the direction of change in demand for aggregate inputs as a result of relative prices change. However, partial equilibrium models cannot inform policy when there are multiple objectives such as searching for an optimal environmental tax that internalises an externality without compromising economic growth and household welfare. Also, given that multiple prices may be changing simultaneously, the partial equilibrium analysis may underestimate or overestimate costs and benefits of environmental policy since the microeconometric simulations are conducted on the assumption that some prices are held constant over the simulation period. Since prices are endogenous in general equilibrium analysis, the CGE approach is appropriate for assessing the economic impact of a fiscal policy regime that taxes high carbon fuels and subsidizes alternative low carbon substitutes.

CHAPTER 5: INTERFUEL SUBSTITUTION AND DYNAMIC ADJUSTMENT IN INPUT DEMAND

5.1 Introduction

This chapter estimates the elasticity of substitution between energy and non-energy factors of production in Malawi using a micropanel model of 59 sectors of the Malawi economy between 1998 and 2004. The chapter also estimates the rate of dynamic adjustment in energy consumption by industrial energy users in response to price changes. The estimated interfuel substitution elasticities and energy and non-energy input substitution elasticities are then used to conduct an environmental policy simulation aimed at reducing energy-related carbon emissions through interfuel substitution. Specifically, the chapter simulates the impact of a subsidy on cleaner fuel sources on carbon efficiency and on biomass conservation in forests.

The rest of the chapter is organized as follows. Sections 2 describes the data and main variables used in the estimation. Sections 3 and 4 discuss the econometric estimates of interfuel demand and aggregate inputs. Estimates of carbon emissions from fuel use and results of policy simulations are presented in section 5. The chapter concludes with some policy suggestions.

5.2 Data and variable definitions

Equations 4.3 and 4.6 were estimated using data from the AES. AES data are collected annually by the Malawi National Statistical Office (NSO). However, reports are only compiled every four years and are summarised at the 3-digit ISIC level. The AES itself is by design a panel of companies selected to reflect the current economic situation in the industrial sector. The variables in AES include sale of goods, stocks, purchases of intermediate materials and supplies used in production, employment, capital investment in fixed assets and profit. Other variables obtained from the AES are production, employment of labour, capital investment and profitability of enterprises. The main variables used in the analysis are summarised in Table 10.

Table 10: Definitions of variables

Variable	Description	Mean	Sd
X_1	Quantity of hydroelectricity purchased in Megawatts	15,568.03	38,345.32
X_2	Quantity of oil purchased in Megawatts	7,222.40	10,944.96
X_3	Quantity of fuelwood purchased in Megawatts	12.31	39.13
X_4	Quantity of coal purchased in Megawatts	114.86	101.50
p_1	Price of 3,413,000 Btu of electricity = price of 1000 Kilowatts of energy	993.23	405.91
p_2	Price of 3,413,000 Btu of oil = price of 1000 Kilowatts of energy	4,738.83	2,736.75
p_3	Price of 3,413,000 Btu of fuelwood = price of 1000 Kilowatts of energy	693.68	218.32
p_4	Price of 3,413,000 Btu of coal = price of 1000 Kilowatts of energy	346.30	203.41
L	Number of workers employed	17,865.45	102,127.40
K	Gross Investment minus depreciation plus changes in stocks in million Malawi Kwacha	30,300.00	180,000.00
E	Energy aggregate in Megawatts	185,467,330.79	295,927,336.65
w_L	Remuneration per worker in Kwacha	538.99	1,189.65
w_K	User cost of capital (Kwacha)	14.33	8.32
w_E	The weighted average price of 1000 kilowatts of energy	511.89	223.55
Y	Output value measured by net sales in million Malawi Kwacha	207.48	842.34

The estimation covers two survey periods from 1998 to 2005. Since the NSO only reports aggregate use and supply figures, micro level energy demand data were obtained by the author from archives of AES questionnaire responses. The data were then aggregated according to activity classifications used by the NSO. Energy data were classified by fuel type, i.e., hydroelectricity, coal, fuelwood, and oil (ethanol, diesel, petrol). All fuels were measured in both physical quantities and monetary values. For uniformity, all energy inputs were converted into British thermal units (Btu) using standard conversion factors from IEA (2003) expressed at Lower Heating Value (LHV)[6]. For lack of unit price data for the fuels, the study uses average prices obtained by dividing total energy expenditures per fuel by corresponding Btu quantities. Bjorner et al. (2001) argue that this is acceptable if the average

[6] Comparable conversion factors can be obtained from the U.S. National Institute of Standards and Technology website.

price is not a function of sales and thus reflects marginal price. In the case of Malawi, virtually all firms are net buyers of fuels and are thus price takers in the energy market.

5.3 Estimates of relative fuel demands and interfuel elasticities

Regression results of the relative fuel demand functions are reported in Table 11. Since equation 4.3 is an unrestricted model of fuel demand, a set of linear restrictions are tested to verify the underlying structure of energy aggregation. Except for coal, demand functions for oil and fuelwood (models 1 and 2) are flexible as they satisfy the following set of restrictions:

a) Test if $\beta_j^X = 0$. Failing to reject the hypothesis that Battese (1997) dummies are equal to zero implies that production technologies at firm level are so different that it is not possible for some firms to use all fuels. Thus, equation 4.3 would be a misspecification since it is not feasible to substitute any of the fuels that a firm currently uses for another that the firm does not use.

b) Test if $\alpha_{ij} = \alpha_{ijm} = 0, \forall i, j, m$. If this condition holds, it means that the energy aggregate used by a firm is composed of fixed proportions of oil, fuelwood, coal and hydroelectricity. Thus, the ratio of quantities of any pair of fuels is constant (Leontief function case) (Mountain and Hsiao, 1989; Mountain, 1989).

c) Unit elasticity of substitution (Mountain and Hsiao, 1989; Mountain, 1989): $\alpha_{ii} = \alpha_{jj} = -1, \forall i, j; \alpha_{ij} = 0, i \neq j; \alpha_{ijm} = 0, \forall i, j, m$. These conditions mean that elasticities of the fuels are restricted to unity and cross-price terms are zero. When these restrictions hold, the unrestricted function reduces to a regular Cobb-Douglas function.

Reading diagonally for the first three variables in Table 11, all demand equations have the expected signs for own-price elasticities. For both oil and fuelwood, demand would increase if the price of any other fuel rises. For coal, demand rises with increases in relative price of fuelwood implying that coal and fuelwood are substitutes but the negative sign on the price of oil suggests a complementary relationship between coal and oil. However, the linear restriction tests show that coal has a slightly different structure as it follows a Cobb-Douglas specification that fails neutral technological change assumption.

Table 11: Fuel-mix regression results

Variable	*Model 1: Oil* $\ln\left(X_2/X_1\right)$	*Model 2: Fuelwood* $\ln\left(X_3/X_1\right)$	*Model 3: Coal* $\ln\left(X_4/X_1\right)$
$\ln(p_2/p_1)$	-1.96 (0.19)*	0.03 (0.12)	-0.07 (0.09)
$\ln(p_3/p_1)$	2.83 (0.85)*	-2.49 (0.50)*	0.25 (0.36)
$\ln(p_4/p_1)$	0.03 (0.48)	3.88 (0.45)*	-0.85 (0.29)*
$[\ln(p_2/p_1)]^2$	0.62 (0.07)*	0.00 (0.06)	0.02 (0.04)
$[\ln(p_3/p_1)]^2$	-0.22 (1.24)	-2.61 (0.77)*	0.34 (0.55)
$[\ln(p_4/p_1)]^2$	-0.24 (0.29)	2.50 (0.34)*	0.61 (0.23)*
$\ln(p_2/p_1)\times\ln(p_3/p_1)$	-1.14 (0.33)*	0.55 (0.23)**	-0.11 (0.17)
$\ln(p_2/p_1)\times\ln(p_4/p_1)$	-0.22 (0.18)	-1.30 (0.17)*	0.27 (0.11)*
$\ln(p_3/p_1)\times\ln(p_4/p_1)$	0.53 (0.50)	-2.14 (0.43)*	-0.97 (0.26)*
t	0.10 (0.03)*	-0.03 (0.02)***	0.02 (0.02)
β_j^X	-0.93 (0.31)*	1.58 (0.23)*	1.06 (0.20)*
Constant	0.62 (0.17)*	-1.63 (0.27)*	-1.04 (0.22)*
Linear Constraints (Chi-squared tests)			
Test for $\beta_j^X = 0$	8.92*	38.61*	19.56*
Test for Leontief restrictions	204.14*	153.27*	52.99*
Unit elasticity (Cobb-Douglas case)	26.57*	7.23*	1.60
Cobb-Douglas linear restrictions	12.28*	19.98*	0.72
Test for $t = 0$	9.03*	6.84*	1.22

* Significant at 1% level ** Significant at 5% level *** Significant at 10% level

The relative demand for coal also failed to satisfy the assumption of neutral technical change. However, coal demand is still influenced by prices of other fuels through interactive price terms. This implies that cross-price effects strongly determine demand for coal and that some fuel prices may fall over time as firms switch to coal. Thus, the time trend in the demand function for coal may be reflecting only expansion in coal production and use due to cheaper prices and not necessarily technological change. Hence firms that use coal are less likely to change their fuel mix because of technological constraints but would shift demand from coal to another fuel only because of price effects.

Allen cross-price elasticities between hydroelectricity and other fuels were estimated and reported in Table 12. Oil and coal are Allen-Uzawa complements to hydroelectricity while fuelwood is a substitute. However, the Allen partial elasticity of substitution is inappropriate in energy studies since it lacks economic meaning. In addition, the estimated demand functions were not symmetric in sign and size of coefficients, hence rendering pairs of cross-price elasticities inconsistent. With three or more inputs, the percentage change in the relative input of factor *i* due to a change in the relative price of factor *j* is a meaningless statistic that holds all other inputs constant, when in fact all inputs adjust to any change in factor prices (Thompson, 2006).

Morishima substitution elasticities were instead estimated for all fuels and reported in Table 12. The MES measures the percent change in the input quantity ratio $\left(X_j / X_1\right)$ with respect to a percent change in the corresponding price ratio $\left(p_j / p_1\right)$. Oil, fuelwood and coal are all Morishima substitutes to hydroelectricity. This implies that it would be possible to switch energy demand from carbon-intensive fuels such as coal and oil to cleaner fuels. It also means that it would be possible to substitute some biomass energy demand for other fuels and hence avert deforestation. The MES between oil and hydroelectricity is comparable to that between fuelwood and hydroelectricity although the MES between fuelwood and hydroelectricity is larger. The MES between fuelwood and hydroelectricity however is almost three times the MES between coal and hydroelectricity. This implies that in all cases relatively more electricity would be used when the other fuel becomes expensive with the greatest response when the price of fuelwood is raised.

Table 12: Allen-Uzawa cross-price and Morishima substitution elasticities

Allen-Uzawa cross-price elasticities			
	Oil	***Fuelwood***	***Coal***
Hydro	-0.65	0.91	-0.39
Oil		0.29	-0.05
Fuelwood	3.79		1.25
Coal	-0.85	3.51	
Morishima Elasticities of substitution			
	Oil	***Fuelwood***	***Coal***
Hydro	1.11	1.42	0.52
Oil		0.49	0.32
Fuelwood	2.67		1.41
Coal	0.36	2.54	

Although oil and coal are Allen-Uzawa complements for hydroelectricity, the Morishima substitution elasticity unequivocally classifies all fuels as substitutes. This is consistent with the observation in several studies including Stiroh (1999), Frondel (2004), and Shankar et al. (2003) that Allen-Uzawa complements might be Morishima substitutes. This is because the Allen-Uzawa elasticity considers the percentage change in an input as a result of a change in any one price whereas the Morishima elasticity measures a change in input ratio resulting from the change in the price of interest. Since the price change affects both inputs in the ratio, it is conceivable that the Morishima elasticity may be positive when the Allen-Uzawa elasticity is negative.

There are sectoral differences in the size of Morishima substitution elasticities for oil, fuelwood and coal paired with hydroelectricity, respectively (Table 13). Activities such as manufacturing of fertiliser and plastics, pharmaceuticals, mining of hard coal and quarrying and bakeries and confectionaries have the greatest potential for switching from oil to hydroelectricity. Thus, these sectors are expected to substantially curb emissions from oil combustion as the price of hydroelectricity falls relative to the price of oil. Manufacturing of sugar and of "soaps, detergents and toiletries" have the lowest MES between hydroelectricity and oil, implying that these sectors would not substantially reduce their carbon emissions from oil combustion even if a revenue-neutral environmental tax was levied on oil offset by subsidies on hydroelectricity. Only the activity of manufacturing fabricated metal and metal stamping use oil as a complement to hydroelectricity, implying that a revenue-neutral environmental tax on oil would almost certainly not change the sector's demand for oil.

Similarly, there would be substantial environmental gains from raising the price of fuelwood relative to the price of hydroelectricity from activities of mining of hard coal and quarrying, bakeries and confectionaries, and fertiliser and plastic products (Table 13). However, tobacco and sugar growing, and manufacturing of sugar, have the lowest potential for substituting fuelwood for hydroelectricity, although between them they use 87 percent of all fuelwood demanded by production activities (NSO, 2001). Thus, these sectors would bear the highest burden of a tax levied on fuelwood proportional to weight of fuelwood used or alternatively, according to equivalent forest area that must be cleared to obtain that amount of fuelwood. The activity of manufacturing fabricated metal and stamping of metal would reduce demand for hydroelectricity by more than 3 percent if the price of fuelwood was raised by 1 percent since hydroelectricity and fuelwood are complements in the activity's production. There is also strong complementarity between fuelwood and hydroelectricity in the manufacturing of soaps, detergents and toiletries whereas for distilling spirits and manufacturing of malt liquor and soft drinks, the complementarity is weak.

For coal, only the activity of distilling spirits and manufacturing malt liquor and soft drinks has elastic Morishima substitution for hydroelectricity. This is important for environmental policy because the sector's demand for coal accounts for 34 percent of all coal use by production activities (NSO, 2001). Thus, a fuel switch from coal to hydroelectricity is possible for at most 34 percent of the coal in the sector. However, the demand for coal by manufacturing of soaps, detergents and toilets is inelastic to change in price of hydroelectricity although the activity uses 63 percent of the coal used by all production activities (NSO, 2001). This means that a carbon tax on coal offset by subsidies on hydroelectricity would disproportionately affect the cost of producing soaps, detergents and toiletries compared to the emissions that may be reduced.

Table 13: Sectoral Morishima elasticity of substitution for hydroelectricity calculated for 1% increase in price of oil, fuelwood or coal.

Sector Name	*Oil*	*Fuelwood*	*Coal*
Tobacco & sugar growing	0.82	0.91	0.18
Tea, coffee & macadamia growing	0.95	1.25	0.31
Mining of hard coal and quarrying	1.51	2.09	0.65
Grain milling	1.17	1.79	0.51
Bakeries and confectionaries	1.43	2.03	0.62
Sugar	0.20	0.58	-0.02
Manufacturing of tea and other food products	0.95	1.25	0.31
Printing (books, music)	1.44	2.03	0.63
Pharmaceuticals	1.58	2.15	0.69
Soaps, detergents and toiletries	0.05	-1.52	0.68
Cement, lime & plaster	1.22	1.84	0.53
Construction	1.23	1.85	0.53
Sale of motor vehicles	1.36	1.96	0.59
Retail of auto fuel	0.89	1.55	0.38
Hardware, paints, and vanish	1.31	1.92	0.57
Other retail sale in specialised stores	1.23	1.85	0.53
Hotels	1.34	1.94	0.58
Restaurants, bars	1.23	1.85	0.53
Horticulture, fishing & forestry	1.19	1.81	0.51
Cattle, dairy & poultry	0.98	1.17	0.29
Meat and dairy products	1.20	1.82	0.52
Textiles and wearing apparel	1.19	1.81	0.52
Publishing	1.22	1.27	0.36
Fertiliser & plastics	1.61	2.18	0.70
Rubber tyres & plastic products	1.15	1.78	0.50
Ceramics and structural metals	1.33	1.94	0.58
Fabricated metal and stamping of metal	-0.25	-3.07	0.62
Batteries & motor vehicle trailers	0.96	1.61	0.41
Maintenance of motor vehicles and sale of spare parts	1.44	2.03	0.63
W/sale on fee and agric raw mate	1.27	1.88	0.55
Retail in non-specialised Stores, Pharmacies and textiles	1.38	1.98	0.60
Distilling spirits/Malt liquor/Soft drinks	0.95	-0.45	1.16

The discussion above suggests that both carbon emissions and forest resource depletion due to industrial fuelwood use could be significantly reduced by changing the relative price of fossil and biomass fuels. This could be achieved for instance by imposing a tax on oil, coal and fuelwood while subsidizing hydroelectricity. In particular, since coal and oil are carbon-intensive but have strong substitution possibilities with hydroelectricity in some sectors, raising the price of these fuels relative to hydroelectricity would significantly reduce carbon emissions. However, some key sectors of the economy such as manufacturing of sugar and of soaps, detergents and toiletries have inelastic demand for hydroelectricity relative to oil, implying that a fossil fuel tax could significantly raise costs for these activities.

Similarly, fuelwood demand responds strongly to relative price changes of hydroelectricity in almost all sectors except for main users of fuelwood namely tobacco and sugar growing, and manufacturing of sugar. Thus, if price effects alone are not enough to reduce fuelwood use by production activities, it would be prudent to focus on sectors that have inelastic demand to find alternative policies that could ensure sustainable use of fuelwood for industrial use. Coal has a large substantial substitution potential for fuelwood. However, it would be inappropriate to support a switch from fuelwood to coal without corresponding carbon tradeoffs.

5.4 Estimates of aggregate energy and labour demand functions

Following the theoretical framework outlined in chapter 4, firms are assumed to combine their least cost fuel mix (the energy aggregate) with other least cost factor inputs. At this input aggregation stage, firms are assumed to combine energy, labour and capital using the same technology with which energy input is aggregated. This assumption is consistent with the assertion that energy mix varies with technology. In this regard, the hypothesis that the rate of dynamic fuel cost adjustment varies across industry is tested. This indirectly tests the proposition by Brannlund and Lundgren (2004) that the rate of dynamic adjustment varies with individual fuel mix.

Estimates of the unrestricted quasi Cobb-Douglas demand functions for labour and energy are reported in Table 14. Both equations were estimated assuming panel specific first order autocorrelation in the residuals. The results show that both relative demand for labour and for energy satisfy regularity conditions and are consistent with theoretical expectations. An increase in the price of energy may lead to a fall in labour demand as indicated by the large negative coefficient for the price of energy. However, there could be some rather weak substitutability between labour and energy in some sectors indicated by small but positive coefficients for the squared price of energy and energy-labour cross-price terms in the labour demand function. Also, an increase in a sector's output will lead to more employment of labour while the positive sign on the Hicks-neutral technical term may be interpreted as indicating expansion of industrial employment of labour over time and that technical progress has favoured labour.

Table 14: Aggregate Energy and Labour demand regressions

Relative demand for labour						Relative demand for energy				
Variables	Coef.	Std. Err.	Z	P>|Z|		Variables	Coef.	Std. Err.	Z	P>|Z|
$\ln(w_L/w_K)$	-0.19	0.05	-3.45	0.00		$\ln(w_L/w_K)$	0.12	0.04	3.17	0.00
$\ln(w_E/w_K)$	-0.74	0.13	-5.52	0.00		$\ln(w_E/w_K)$	-0.93	0.08	-12.20	0.00
$[\ln(w_L/w_K)]^2$	-0.04	0.02	-2.79	0.01		$[\ln(w_L/w_K)]^2$	0.02	0.01	2.53	0.01
$[\ln(w_L/w_K)]\times[\ln(w_E/w_K)]$	0.07	0.03	2.63	0.01		$[\ln(w_L/w_K)]\times[\ln(w_E/w_K)]$	-0.04	0.02	-2.38	0.02
$[\ln(w_E/w_K)]^2$	0.06	0.10	0.61	0.54		$[\ln(w_E/w_K)]^2$	0.34	0.07	4.97	0.00
$\ln Y$	0.08	0.05	1.70	0.09		$\ln Y$	-0.88	0.05	-16.88	0.00
t	0.26	0.09	2.74	0.01		t	0.07	0.07	1.08	0.28
$\ln(L/K)_{t-1}$	0.12	0.04	2.82	0.01		$\ln(E/K)_{t-1}$	0.02	0.01	2.30	0.02
β_2	-2.88	0.42	-6.85	0.00		β_3	18.11	0.36	50.26	0.00

For aggregate energy demand however, an increase in the price of labour could lead to an increase in demand for energy which might be offset if the energy-capital price ratio in the cross-price term is large. Also, as in the case of labour, the positive sign on the Hicks-neutral technical term indicate that energy use by industrial sectors is expanding over time and that energy demand and capital adjust in the same direction. However, the negative sign on output implies that output growth does not necessarily lead to an increase in energy demand but rather that firms may be using energy inefficiently at low levels of output. Thus, growth in demand for a firm's output may lead to considerably energy savings over time.

In both demand equations for labour and energy, the dynamic adjustment parameter (λ) is positive and significant which is consistent with the Le Chatelier principle that short-run elasticities can never be greater than long-run elasticities in absolute value (Urga and Walters, 2003). The rate of adjustment for labour-capital ratio to its desired level is 88 percent $(1-\lambda)$

annually whereas energy-capital ratio adjusts by 98percent[7]. The high adjustment speed has important implications for the effectiveness of policies aimed at curtailing energy use in the economy. In particular, energy conservation policies may be costly if the introduction of energy-efficient capital is pursued while capital and energy are net complements in production or when the rate of dynamic adjustment is slow. Since we found substitution among fuels within the energy aggregate, energy conservation can be pursued with little or no labour effects in the short-run. However, the results show that firms adjust energy demands much faster than labour, implying that production sectors almost always match actual energy-capital ratios at their desired levels but afford mistakes with labour projections. The cumulative impact of projection errors on labour employment could be significant in the long run if energy policies are unpredictable.

To test the hypothesis that adjustment speed varies across industries, the rate of dynamic adjustment (λ) was multiplied by the observed lagged values for labour-capital and energy-capital ratios in log form, respectively (Table 15). The resulting values were compared across industries using one-way analysis of variance. For labour, the test statistic $(F(5,216)=2.23)$ is barely significant at 5 percent level while for energy, the test statistic $(F(5,216)=3.09)$ is significant at 1 percent level. In both cases however, the null hypothesis of equal variances cannot be rejected by the Bartlett's test. Further exploration of the adjustment structure revealed that for labour demand, services, mining and manufacturing have the highest long-run adjustment speeds with respect to labour-capital changes while agriculture and services have the highest long-run adjustment speeds with respect to energy-capital changes.

Table 15: Relative input adjustment speeds across industry

	Labour-capital adjustment speed			Energy-capital adjustment speed			Labour-energy adjustment speed*		
Industry.	Mean.	Sd.	Freq.	Mean.	Sd.	Freq.	Mean.	Sd.	Freq.
Agriculture	-0.21	0.22	28	0.15	0.12	28	-2.36	1.95	28
Manufacturing	-0.15	0.26	117	0.07	0.12	117	-1.89	2.10	117
Services	-0.1	0.18	14	0.14	0.17	14	-2.12	2.21	14
Mining	-0.14	0.25	7	0.06	0.12	7	-2.06	1.95	7
Distribution	-0.26	0.32	49	0.09	0.12	49	-2.24	2.18	49
All Industries	-0.18	0.27	215	0.09	0.13	215	-2.13	2.10	215

* Labour-energy adjustment is presented here for comparison only since it was calculated from regression of Labour normalised by energy aggregate.

[7] For comparison, a labour-energy regression was estimated on the assumption that energy is quasi-fixed while capital is variable. Firms adjust their labour at the rate of 87% annually to the desired labour-energy ratio. This is comparable with the rate at which firms adjust labour to the desired labour-capital ratio.

Capital and energy have theoretically consistent Allen own-price elasticities (Table 16). Labour however has inconsistent own-price elasticity which can be explained by the large share of labour in production costs for most industries. In fact, the average share of labour in total cost over the entire estimation sample is 76percent. Capital and energy are moderately responsive to own-price changes but energy is more than twice as responsive as capital. The Allen-Uzawa cross-price elasticities show that capital and labour are complements, although the elasticity is quite low. However, energy and capital are Allen-Uzawa substitutes and that a change in the price of capital could trigger a large response in demand for energy.

The substitution possibility between energy and capital is verified by the MES. However, the extent of substitution possibility is significantly lower than suggested by the Allen-Uzawa substitution elasticity. Whereas labour and capital are Allen-Uzawa complements, the Morishima substitution elasticity suggests otherwise with a significantly large substitution possibility (Table 16). The elasticity of substitution between capital and labour and between capital and energy are fairly symmetric, suggesting that the underlying cost function is close to the constant elasticity of substitution formulation.

Table 16: Allen-Uzawa and Morishima elasticities

Allen-Uzawa own and cross–price elasticity of	Capital	Labour	Energy
Capital	-0.32	-0.03	21.61
Labour		0.01	-0.03
Energy			-0.65
Morishima substitution elasticity of	Capital	Labour	Energy
Capital		0.90	1.57
Labour	0.85		-0.62
Energy	1.58	-0.20	

Labour and energy are Morishima complements but energy-labour ratio is very responsive to adjustments to the relative price of labour. This result could similarly be explained by the relatively high share of labour in total production cost compared to the share of energy. Thus, a large compensating change in the energy-labour ratio is required for a given change in the price of labour. Thus, labour intensive activities are in general energy-using production technologies.

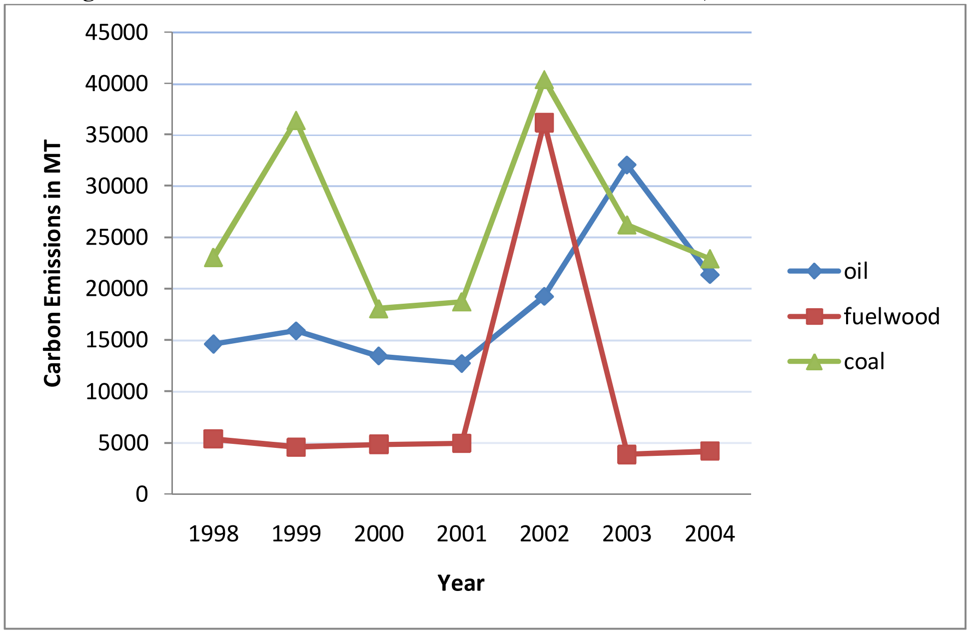
Long-run own- and cross-price elasticities provide better parameters on which to base projections for future labour and energy scenarios. This is calculated by dividing the short-run elasticity with the corresponding dynamic adjustment coefficient. In this regard, the adjustment parameter in the labour demand equation suggests that the long-run Allen own elasticity of capital is $-2.67 = \left(\frac{-0.32}{0.12}\right)$, and that of energy is -5.17. In addition, the long-run (Allen-Uzawa) cross-price elasticity of capital to labour is -0.25 and that of energy and labour, based on the more realistic Morishima, is -5.17. From the results above, policies that reduce labour intensity and increase capital intensity will contribute to lower energy use in the Malawi economy. As energy-efficient capital replaces existing physical capital, lower energy intensities would be realized per unit of output produced. However, such a policy is likely to impact negatively on labour employment since energy and labour are Morishima complements whereas capital and labour are Morishima substitutes.

Although labour effects can be inferred from estimates of substitution elasticities, the results from the aggregate regressions above only partially explain the link between interfuel substitution and the final composition of the energy aggregate. In section 5.3 we showed that there were differences in sectoral reaction to changes in relative prices of fuels. The implication of that result and the discussion above is that both economic and environmental outcomes can be influenced by manipulating the composition of the energy aggregate through prices. In the next section, we explore the possibility of reducing energy-related emissions and deforestation with energy taxes and subsidies and estimate, with several caveats, the resulting changes in emissions and fuelwood extraction.

5.5 Estimates of carbon emissions and policy simulations

Actual demand data for fuels and emission coefficients from IEA (2003) were used to calculate carbon emissions by sector and by fuel over time. Industrial use of coal is the largest source of carbon emission despite the fact that it was used by only three sectors. This result reflects the intensity of use of coal in the three sectors compared to the use of other fuels by all other sectors. The only time carbon emissions from fuelwood combustion were above oil related emissions was between 2001 and 2002 (figure 1) when Malawi had frequent power outages due to technical problems caused by floods and siltation at ESCOM main power generating station on Shire River.

Figure 2: Annual carbon emissions from industrial use of oil, coal and fuelwood



The activity of manufacturing of soaps, detergents and toiletries is a key sector as it accounts for 66.8 percent of carbon emissions from coal. The sector that distils spirits, and manufactures malt liquor and soft drinks is also an important activity as it accounts for 33.2 percent of the carbon from coal and 30 percent of oil related carbon emissions. The growing of tea and manufacturing of "tea and other products" are key sectors for deforestation as they account for 67.6 percent of fuelwood demand by production activities and about 8 percent of oil related carbon emissions. Tobacco and sugar growing, and the manufacturing of sugar are equally important for deforestation as together account for 27.4 percent of fuelwood demand by production activities.

Using these statistics and the Morishima elasticities estimated at the energy aggregation stage, two environmental policy implications can be drawn. First, since hydroelectricity and fuelwood are substitutes, deforestation associated with industrial fuelwood use could be reduced if the price of fuelwood is raised relative to the price of hydroelectricity or investing in more hydropower. Second, a large proportion of energy-related greenhouse gas emission reductions could be achieved by raising the prices of coal and of oil relative to the price of hydroelectricity, respectively. Since the Morishima elasticity is higher for oil than for coal, one could expect more greenhouse gas emission reductions to be achieved by slightly raising the price of oil to promote substitution towards hydroelectricity. This however will lead to larger increases in fuelwood use and hence more deforestation. On the other hand, to reduce fuelwood use and deforestation the highest potential substitution is in coal. However, more coal implies more emissions since coal has higher carbon content than any other fossil fuel.

In order to clarify the suggestions above, two environmental simulations were conducted in MS Excel Solver using the regression results and actual elasticity estimates. The first simulation was aimed at minimizing emissions from fuelwood, hence indirectly minimizing the contribution of industries to deforestation. The reasoning is that for every ton of carbon abated from fuelwood combustion, at least two tons of fuelwood biomass could be conserved (Girard, 2005). The policy scenario is one where a subsidy on hydroelectricity is envisaged within a range of 0 to12.5 percent, while ad valorem tax on fuelwood is expected to range from zero to 35percent. The subsidy of 12.5 percent on hydroelectricity is half the maximum subsidy envisaged under the rural electrification project while the maximum tax rate is set at 35 percent to coincide with the maximum income tax rate in Malawi[8].

The starting values for MS Excel Solver were 5 percent subsidy on hydroelectricity, 2 percent tax on oil, 5 percent tax on fuelwood and 3 percent tax on coal. At these fiscal values, a total of 1.67 megatons of carbon from fuelwood combustion would have been averted over the projection period (1998 to 2004). This translates to 3.34 megatons of biomass that could have been maintained as standing forest stock. The solver solution is a total abatement of 16.25 megatons of carbon or equivalently 32.5 megatons of biomass maintained as standing forest stock. This however is achieved only after implementing a 12.5 percent subsidy on hydroelectricity, a 35 percent tax on coal but zero tax rating on oil and fuelwood.

The second simulation was aimed at reducing total energy-related carbon emissions. The same starting values as above were used in MS Excel Solver. At these fiscal values, an additional 0.2 megatons of carbon would have been emitted from coal while 0.68 megatons would have been abated from oil, representing a total emission reduction of 22.55 megatons of carbon after factoring in abatement from fuelwood. The solver solution is a total abatement of 19.35 megatons of carbon consisting of 61.6 percent from fuelwood, 36.4 percent from oil and 2 percent from coal. These reductions in emissions are achieved only after implementing

[8] This was reduced from 35% to 30% during the 2006/2007 Financial Year (GoM, 2006).

a 12.5 percent subsidy on hydroelectricity and levies of 35 percent tax on fuelwood and coal, respectively. The price of oil is however left at benchmark value.

These simulation results have several implications for environmental policy. First, if the focus of environmental or energy policy is conservation of biomass in forests, the highest rate of conservation could be achieved by levying a tax on coal while subsidizing hydroelectricity. However, no tax on fuelwood is required to achieve a maximum reduction in fuelwood use in industry. This result is consistent with Morishima elasticities estimated above since a subsidy on hydroelectricity and zero tax on fuelwood make hydroelectricity relatively cheaper than fuelwood. Second, if environmental or energy policy is aimed at reducing total carbon emissions, the greatest gain would come from reducing fuelwood use albeit at a maximum tax rate of 35 percent for fuelwood and coal, respectively, and a maximum subsidy of 12.5 percent for hydroelectricity.

5.6 Summary and conclusions

The chapter estimated interfuel substitution elasticities in the energy aggregate and also capital, labour and energy substitution elasticities for Malawian production sectors. The rates of dynamic adjustment in demand for labour and energy were presented in addition to potential environmental gains from abatement of energy-related carbon emissions in industry.

Several insights were drawn from the main findings of the chapter. One of the results was that the structure of relative demand for oil and fuelwood were relatively flexible implying that oil and fuelwood users have high potential for substituting other fuels under energy policy constraints. Coal users on the other hand have limited substitution alternatives although fuelwood emerged as a key substitute. Thus, coal users are unlikely to change their energy mix over time but would respond to relative fuel price changes. This implies that the potential for reducing emissions from coal is limited first by technology and second, by the environmental tradeoffs of increasing fuelwood use and the resulting deforestation. Hence, coal users would have the highest tax incidence when the thrust of environmental policy is to maintain biomass in standing forests. Coal and fuelwood users would also face the highest tax rates when environmental policy focuses on abating total energy-related carbon emissions.

Another finding was that Morishima interfuel elasticities and dynamic demand adjustment rates vary considerably across sectors. This has important implications for policy efficacy in that the sectors with high dynamic adjustment rates face lower transition costs (high benefits) as environmental taxes (subsidies) are imposed on various fuels. In addition, labour and energy employment impacts of environmental taxation would be lower for sectors with high adjustment rates. Therefore, to minimize the distributional impacts of energy taxes, the best option would be to reduce fuelwood use in industry by levying taxes on coal while subsidizing hydroelectricity. From fuel demand data, the tax burden would be heavily borne by the producers of soaps, detergents and toiletries and distilled spirits, malt liquor and soft drinks. On the other hand, when carbon taxes are implemented with the view to reducing total emissions, the growing of sugar, tea and tobacco and the manufacturing of tea and other products would bear the greatest burden. Since tobacco, tea and sugar are main export commodities accounting for over 80 percent of export earnings (FAO, 2003) the economic cost of carbon abatement may outweigh the environmental benefits.

Given the tradeoffs between increasing emissions and worsening deforestation, there is need to quantify the total economic costs of policies that aim at shifting energy mix from carbon-intensive fuels and biomass sources to hydroelectricity. The environmental costs of deforestation may be higher than the cost of additional carbon emissions. According to GoM (1994), the social cost of deforestation was US$55 million (2.7 percent of GDP) estimated by the replacement values of wood harvested above the sustainable yield and by reduced crop yield as a result of increased incidence of soil erosion. This estimate is rather conservative as other costs such as sedimentation of main rivers and their impacts are not included.

The results also suggest that policies that reduce labour intensity and increase capital intensity will lower energy use. However, since labour and energy are Morishima complements while capital and labour are substitutes, investing in energy saving capital equipment may increase unemployment over time. The dynamic adjustment parameters also showed that energy-capital ratios are adjusted at a faster rate than labour-capital ratios, implying therefore that unemployment costs may take hold within a short period. As a consequence, the long-run environmental gains from energy saving investments in capital could be lower than economic welfare losses resulting from unemployment.

Thus, to evaluate the net effect of shifting demand from fuelwood and fossil fuels (oil and coal) to hydroelectricity, there may be need to evaluate multiple objectives using either multi-criteria programming or CGE modelling to evaluate policies that give double or triple dividends in terms of smaller reductions in economic growth, lower emission and less deforestation. One objective could be investing in energy-efficient capital as a strategy for improving both energy efficiency and environmental quality in Malawian industrial sector. Although the econometric results suggest negative impacts on employment from capital-labour and energy-labour substitutions, it is conceivable that labour employment impacts may be dampened by growth elsewhere in the economy, especially in agriculture and mining. This proposition could be validated using a CGE model.

CHAPTER 6: THE CGE MODEL AND ITS POLICY SIMULATION RESULTS

6.1 Introduction

In this chapter, calibration and policy simulation results of the CGE model for assessing the implication of shifting the energy mix of the Malawi economy from biomass and fossil fuels to hydroelectricity are presented. In particular, the distributional effects of an environmental policy regime that taxes high carbon fuels and subsidizes alternative low carbon substitutes are discussed. One proposition is that the impact of carbon taxes would be negative for capital intensive sectors but positive for labour intensive sectors because capital intensive sectors are also energy intensive. Also, it is expected that the positive impact of fiscal policy regimes that taxes high carbon fuels and subsidizes alternative low carbon substitutes on labour intensive sectors would offset the negative impact on capital intensive sectors resulting in a positive overall net economic impact (gains). Thus, within the limits of these two propositions, the viability of simultaneous environmental and welfare improvements (double dividend) from a fiscal policy regime that taxes high carbon fuels and subsidizes alternative low carbon substitutes would be assessed.

The model used in this chapter is heavily restricted by data availability. In particular, virtually all energy sectors are aggregated to a level that prevents use of fuel switching technologies to simulate emission reduction by production sectors. The implication is that policy simulations may overestimate the cost of emission reduction in the sense that output reductions are exaggerated to some extent (Jorgenson and Wilcoxen, 1993; Fullerton and Metcalf, 1997; Fischer, 2001). To reduce output loss due to emission taxes, other studies use output-rebated emission taxes to achieve revenue neutrality albeit with the understanding that for any given emission rate, output-based rebating induces less total emission reduction (Fischer, 2001). Alternatively, this chapter adopts the approach that assumes that emissions and resource extractions have a small but positive elasticity of substitution with output. This minimizes the inefficiency of the model in predicting general equilibrium impacts of environmental taxes.

The rest of the chapter is organized as follows. Calibration of the general equilibrium model is discussed in section 2 while section 3 presents the design of environmental policy simulations. Sections 4 and 5 discuss the results in terms of economic and environmental implications, respectively. Section 6 concludes the chapter.

6.2 Calibration of the general equilibrium model

The International Food Policy Research Institute (IFPRI) SAM for Malawi was used to calibrate the model. The IFPRI SAM is the most reliable database on which to calibrate CGE models for Malawi. A full documentation of the SAM is Chulu and Wobst (2001). Lofgren (2000; 2001) provide a full documentation of the standard CGE model for Malawi. Although this study has some similarities with Lofgren's specification of the model, there are subtle differences in the assumptions used to derive equilibrium. Also, unlike Lofgren (2001), a one-to-one correspondence is imposed between activities and commodities (Table 17) as it is assumed that the loss of information from aggregating large-scale and small-scale agricultural activities is negligible. The algebraic specification of the model is in the appendix.

To model substitution between fuels in the energy aggregate, and between energy and non-energy inputs, the data in the Malawi SAM should ideally be disaggregated to show energy flows among industries (intermediate demand for energy), energy flows between industries and final consumers (final demand for energy), primary factor demands by energy producing industries, taxes on energy and imports of energy products. With this structure, emission reduction can be achieved by imposing an energy sales tax to minimize the energy sector's footprint on the environment.

The Malawi SAM is not fully disaggregated by energy activities. Except for AOIL, all other energy producing activities have concurrent production of non-energy outputs. For instance, AMINE has coal and other mining products such as lime and quarry stone, AFORE has other forestry products apart from fuelwood while AELEC has water and hydroelectricity (Table 17). However, using fuel demand data from AES and carbon emission coefficients from IEA (2003), the Malawi SAM is extended to include disaggregated data on activity level carbon emissions from fossil fuels, as well as quantities of biomass and hydroelectricity demanded. The IEA macro-level data is also used to check consistency of AES data as it relates to energy intermediate use.

Table 17: Description of SAM accounts

	ACTIVITY	ACTIVITY DESCRIPTION	INDUSTRY
1	AMAIZ	Maize (only small-scale)	Agriculture
2	ATEA	Tea and coffee	Agriculture
3	ASUGA	Sugar growing (only large-scale)	Agriculture
4	ATOBA	Tobacco growing	Agriculture
5	AFISH	Fisheries	Agriculture
6	ALIVE	Livestock and poultry	Agriculture
7	AFORE	Forestry	Agriculture
8	AOTHA	Other crops	Agriculture
9	AMINE	Mining	Mining
10	AMEAT	Meat products	Manufacturing
11	ADAIR	Dairy products	Manufacturing
12	AGRAI	Grain milling	Manufacturing
13	ABAKE	Bakeries and confectioneries	Manufacturing
14	ASUGP	Sugar production	Manufacturing
15	ABEVE	Beverages and tobacco	Manufacturing
16	ATEXT	Textiles and wearing apparel	Manufacturing
17	AWOOD	Wood products and furniture	Manufacturing
18	APAPE	Paper and printing	Manufacturing
19	ACHEM	Chemicals	Manufacturing
20	ASOAP	Soaps, detergents and toiletries	Manufacturing
21	ARUBB	Rubber products	Manufacturing
22	ACEME	Non-metallic mineral products	Manufacturing
23	AMETA	Fabricated metal products	Manufacturing
24	AMACH	Plant and machinery	Manufacturing
25	AELEC	Electricity and water	Utilities
26	ACNST	Construction	Construction
27	AOILD	Oil distribution	Services
28	AAGRD	Agricultural distribution	Services
29	AOTHD	Other distribution	Services
30	AHOTE	Hotels, bars, and restaurants	Services
31	ATELE	Telecom and transportation	Services
32	ABANK	Banking and insurance	Services
33	ABUSI	Business services	Services
34	APUBS	Public services	Services
35	APERS	Personal and social services	Services

Source: Chulu and Wobst (2001)

Both the IEA (2003) and AES data consistently show that manufacturing emits most of the energy-related carbon, while agriculture contributes the lowest to energy emissions (Table 18). Some of the carbon emissions are from construction, mining, and services, although together these sectors contribute less than 8 percent of the emissions. Manufacturing also has the highest pressure on forests as it uses most of the fuelwood and is important for shifting energy demand by production activities as it uses most of the hydropower supplied to production activities. Agriculture, on the other hand, is also an important sector for biomass energy management as it uses a significant amount of fuelwood.

Table 18: Sectoral biomass use (%) and carbon emissions (%)

Sector	Hydroelectricity use (%)	Biomass use (%)	Carbon emission (%) from oil and coal
Agriculture	6.6	20.6	0.4
Mining	6.8		2.3
Manufacturing	79.0	79.4	92.1
Utilities			
Construction	1.5		2.9
Services	6.0		2.3
TOTAL	100	100	100

Source: 1998-2000 AES, NSO (2001)

The services sector was important for generating most income in the economy in 1998, followed by agriculture (Table 19). The share of labour in value added suggests that mining, services and agriculture spend relatively more on labour, respectively, than other sectors. Manufacturing, utilities and construction spend relatively more on capital than on labour. Thus, mining, services and agriculture are typically labour intensive, while manufacturing is capital intensive. For agricultural activities however, the value of land is almost twice the value of capital input reflecting the extent of land expansion by small-scale agriculture compared to capital investment by large-scale agriculture.

Table 19: Sectoral generation of income in 1998 SAM for Malawi

Industry	Value added (VAD) (%)	Labour income in VAD (%)	Capital income in VAD (%)	Land income in VAD (%)	VAD in Gross output (%)
Agriculture	35.9	53.4	16.4	30.2	64.3
Mining	1.3	76.3	23.7		91.4
Manufacturing	14.8	34.1	65.9		25.6
Utilities	1.5	43.6	56.4		26.2
Construction	2.3	43.6	56.4		35.7
Services	44.2	64.9	35.1		72.0
Total	100.0	55.6	33.6	10.8	53.0

Source: 1998 IFPRI SAM for Malawi

The distribution of factor earnings to households shows that labour is the main source of income for all rural households, especially those with less than 2 hectares of landholdings (Table 20). However, rural agricultural households with between 2 and 5 hectares of land earn proportionately equal income from land and labour. On the other hand, urban agricultural households earn relatively more from labour than rural agricultural households with more than 5 hectares of landholdings possibly because they have alternative employment opportunities. For rural households, the proportion of earnings from capital tends to increase with a household's landholding. For urban non-agricultural households, capital is the main source of income and the proportion of earnings from capital increases with household's education level. Labour is the sole source of income for all rural non-agricultural households and urban non-agricultural households with no education.

The results above are further clarified by lumping together rural and urban households and then comparing the spatial distribution of factor incomes. This reveals that rural households get 72 percent of all the labour income while urban households get 93 percent of all the capital income. Rural households also get about 57 percent of the land rents with the remainder going to urban households. Thus, rural households are labour and land endowed while urban households are capital endowed.

Table 20: Household type and factor income sources (%)

Household type	Labour	Land	Capital	Total
Rural agriculture less than 0.5 ha landholding	97	2	1	100
Rural agriculture between 0.5 ha and 1.0 ha landholding	93	5	2	100
Rural agriculture between 1.0 ha and 2.0 ha landholding	91	7	2	100
Rural agriculture between 2.0 ha and 5.0 ha landholding	42	43	15	100
Rural agriculture more than 5.0 ha landholding	4	64	31	100
Rural non-agriculture no education	100			100
Rural non-agriculture low education	100			100
Rural non-agriculture medium education	100			100
Rural non-agriculture high education	100			100
Urban agriculture	33	44	23	100
Urban non-agriculture no education	100			100
Urban non-agriculture low education	8		92	100
Urban non-agriculture medium education	37	5	58	100
Urban non-agriculture high education	30	6	64	100

Source: 1998 IFPRI SAM for Malawi

Households also differ by the type of goods and services demanded. Grain is an important component of expenditure for all households but rural households spend relatively more on grain and other crops than urban households (Table 21). Public services are also a significant proportion of household expenditure for both rural and urban households while telecommunication and transportation services are important for urban agricultural households. Urban non-agricultural households also spend a significant proportion of their income on hotels, restaurants and bars, and on chemicals.

Table 21: Household consumption expenditure shares (%) for the CGE model

Commodity	Rural Agricultural	Rural Non-Agricultural	Urban Agricultural	Urban Non-Agricultural
Grain milling	25.4	23.2	16.7	14.0
Other crops other than maize, tea, tobacco and sugar	15.0	14.7	10.1	8.3
Fish	1.0	1.2	0.9	0.2
Meat products	6.5	6.2	7.1	4.4
Dairy products	0.5	0.9	1.9	2.6
Bakeries and confectioneries	1.0	1.8	2.4	2.2
Sugar	2.0	3.1	3.0	3.3
Beverages and tobacco	9.3	7.2	1.9	3.8
Textiles and wearing apparel	6.6	8.3	6.1	6.8
Wood products and furniture	2.5	2.7	3.0	6.0
Paper and printing	0.2	0.3	0.4	0.5
Chemicals	2.3	3.5	6.5	7.1
Soaps, detergents and toiletries	3.6	4.7	2.3	2.1
Rubber products	0.3	0.7	1.2	1.4
Non-metallic mineral products	0.8	0.9	1.0	0.8
Fabricated metal products	0.7	0.9	1.2	1.1
Electricity and water	0.4	0.6	0.7	2.9
Hotels, bars, and restaurants	3.0	3.4	6.3	10.2
Telecommunication and transportation	2.8	2.2	12.6	6.9
Banking and insurance	0.3	0.7		5.1
Business services	0.1		0.2	0.5
Public services	15.4	12.3	9.7	7.5
Personal and social services	0.9	1.2	4.8	5.0
Total	**100**	**100**	**100**	**100**

Source: 1998 IFPRI SAM for Malawi

Table 22 shows production cost shares for the CGE model. Utilities, construction, and manufacturing sectors have relative high cost shares (>59 percent) for intermediate goods while mining has the lowest cost share for intermediate inputs. Aggregate energy cost shares are generally low, ranging from 2-4 percent except in manufacturing where energy costs are 9 percent of production costs. Capital cost shares are fairly even across sectors except agriculture and utilities which have low capital cost shares, relatively. For agriculture, the cost shares for labour and intermediate inputs are equal while for services, and consistent with the distribution of value added in Table 19, labour costs almost twice as much as intermediate inputs.

Manufacturing, utilities and construction have capital-labour ratios of greater than 1 implying that they are relatively capital intensive while agriculture, mining and services have capital-labour ratios of less than 1 implying that they are labour intensive (Table 22). For agriculture, the capital-labour and the land-labour ratios are quite close, reflecting the structure of production among small-scale farmers who may be using land and capital as if they are substitutes. This is consistent with the observation by Wobst et al. (2004) that for small-scale agricultural activities the land-capital ratio is fixed so that capital shifts basically reflect land shifts. For all sectors, the capital-energy and labour-energy ratios are large mirroring the low energy cost shares.

6.3 Design of environmental policy simulations

To induce a shift in the energy mix from biomass and carbon-intensive fuels to hydroelectricity, the study simulates Pigouvian taxes on carbon emissions. Also, following Bruvoll and Ibenholt (1998), a material throughput tax on fuelwood is implemented to reduce the quantity of fuelwood input used by production activities. Consistent with Burniaux et al (1992), the material throughput tax is an excise tax levied on each ton of fuelwood. The resulting tax rate is levied specific to fuelwood using sectors and it varies with fuelwood use intensities. This is simultaneously implemented with an *ad valorem* subsidy on hydroelectricity to offset a rise in energy cost associated with taxes on fossil fuels and fuelwood. Specifically, the simulations are designed as follows:

Simulation 1:

Let the regulator set targets for carbon emissions from fossil fuels (coal and oil). Since Malawi has zero Kyoto Protocol targets, the targeted reductions of the benchmark total emissions ranges from 6 percent to 12percent. In simulation 1, the targeted reduction in emissions coincides with half of the average rate of increase in cumulative emissions from sub-Saharan African countries from 1990 to 1998 (i.e., 6percent). This is rather conservative considering that Malawi’s own emissions grew by an annual average of 17 percent during the 1990-1998 period, and by about 42 percent annually up to year 2005 (World Resources Institute, 2008).

Hydroelectricity is a produced commodity and is represented in the SAM based on monetary valuation of factors, goods and services flows in the economy. However as shown in chapter 1 and 2, effective demand for hydroelectricity is less than 50 percent of generated output. This therefore allows the environmental regulator, who is also the sole generator and distributor of hydroelectricity to arbitrarily set targets for increased demand by production activities. This is implemented in the form of a subsidy on hydroelectricity since partial equilibrium results revealed substitution possibilities between hydroelectricity and oil and coal, respectively. Since the projected increase in demand as a result of subsidies is consistent with installed generation capacity of hydroelectric *vis a vis* effective demand, the proposed subsidy rate coincides with half the subsidy value envisaged under the rural electrification project.

Similarly, fuelwood in the Malawi SAM is a produced commodity by Forestry activity. However, by introducing physical quantities of fuelwood demanded by production activities in the extended SAM, we can simulate the impact of reducing physical demand of fuelwood by production activities. This is implemented in the form of a unit excise tax on a ton of fuelwood demanded. The unit excise tax rate on fuelwood is premised on the need to manage deforestation risk. In this regard, the rates of loss of forest cover between 1990 and 2005, and of primary cover between 2000 and 2005 are assumed as the lower and upper bounds for taxes to reduce fuelwood use by production activities. According to Butler (2006), the loss of forest cover between 1990 and 2005 was 13percent, and between 2000 and 2005, the country lost about 35 percent of primary forest cover. However, since some of the deforestation is caused by household use of fuelwood, the upper bound is set at 24percent, which is the average between the assumed values for low (13percent) and high deforestation rates[9]. It is therefore assumed that the excise tax levied on fuelwood is MKW 0.13 per kg or MKW130 per ton of fuelwood.

Simulation 2:

Cut carbon emissions by 12 percent and raise fuelwood excise tax to MKW 0.24 per kg or MK240 per ton while simultaneously implementing a 12.5 percent subsidy on hydroelectricity as a cost offsetting strategy. As indicated above, 12 percent reduction in carbon emissions is consistent with the average annual growth rate in cumulative emissions from sub-Saharan Africa from 1990 to 1998. The other figures for subsidy on hydroelectricity and excise tax on fuelwood are based, as above, on proposed rates of subsidy for rural electrification and on estimated loss of forest cover, respectively. Simulation 2 is the most stringent environmental policy stance as both carbon emissions and fuelwood demand are heavily constrained.

[9] Although there is no linear correspondence between fuelwood use and observed deforestation rates, it is important for policy purposes to target objective and measurable variables that impact on deforestation rates. In this case, fuelwood use intensities and physical fuelwood demands per sector are key factors.

Simulation 3:

Carbon emissions are allowed to increase by up to 1.5 percent above the benchmark. This is implemented simultaneously with a MKW 0.24 per kg excise tax on fuelwood while simultaneously subsidizing hydroelectricity by 12.5percent. In addition, the virtual price of carbon emission permit is set at minimum of zero but flexible upward to ensure that there is no pecuniary cost on government for relaxing the carbon constraint on producers. This simulation is arbitrary and is used to demonstrate that other policies except direct taxes on carbon emissions could be used to control energy-related carbon emissions in developing countries.

6.4 Economic implications of environmental policy

The environmental policy simulations described above have implications for not just the environment but also the economy. The economic impacts are evaluated in terms of relative changes in output, household welfare (utility), government revenue and current consumption, and national savings and investment. In all cases, the changes are evaluated as a percent change with respect to benchmark values. All the CGE simulation results are in the appendix.

6.4.1 Household welfare

Aggregate household welfare measured by utility of a representative household marginally decline when environmental revenues are pooled with other government revenues with the only exception when the carbon constraint is nonbinding. On the other hand, recycling of environmental revenues improves welfare of the representative individual (Table B1). While a non revenue-neutral environmental policy is damaging for almost all urban agricultural households and rural households with large landholdings, the greatest welfare gain (loss) for disaggregated households is when environmental policy is stringent and revenues are (not) redistributed to households (simulations 2). A nonbinding carbon constraint is welfare improving in both revenue-neutral and non-neutral cases and would generally benefit non-agricultural households (simulation 3). Hence, not all households are equally affected by tax and subsidy policy on carbon emissions, fuelwood and hydroelectricity.

Simulations 1 and 2 lead to welfare losses for all households except rural households with large landholdings and for one urban agricultural household category when environmental revenues are pooled with other government funds. In contrast, recycling of additional environmental tax revenues to households improves welfare of virtually all agricultural households except those with large landholdings. However, recycling of revenue to households may not benefit urban non-agricultural households as they suffer marginal welfare losses.

These results can be explained by the fact that the main sources of income for rural households (i.e., the various labour categories) marginally gain value regardless of how additional environmental tax revenues are utilized while prices of some main consumption commodities (beverages and tobacco, and soaps and detergents) rise by between 4 and 30 percent(Tables B2 and B9). Similarly, urban non-agricultural households with low or medium education attainment get most of their income from either labour or non-agricultural capital whose values either declined or slightly increased, respectively, while prices of main consumption commodities such as meat, beverages and tobacco, and hotels, bars and restaurant services have gone up.

With recycling of environmental tax revenues, all rural agricultural households are welfare gainers, with the greatest gain of 7.25 percent by households with between 2 and 5 hectares of landholding (Table B1). Although large-scale land values do not increase by much, rural households with between 2 and 5 hectares of landholding have more diverse sources of income including medium education labour (both agricultural and non-agricultural), land and capital. Increased productions of cash crops such as tobacco, tea and coffee which are typically produced by households with large landholdings also have positive impact on incomes and welfare of these households (Tables B1 and B4).

All agricultural households are welfare winners when the regulator recycles environmental revenue to reduce the burden of direct taxes on households. The decision to recycle revenues to reduce direct tax obligations favours low income agricultural households because factor incomes to small-scale land owners consistently and significantly rise (Table B5). However, it is households with landholdings of between 2 and 5 hectares that have the highest welfare improvement as explained above (Tables B1 and B4). This suggests that smallholder farmers who are not land constrained would benefit as they could diversify production since increases in factor earnings are also accompanied by increases in production of cash crops such as tea, coffee and tobacco. Although the extra production of cash crops leads to a fall in relative prices of most agricultural commodities (Table B9), the change is so insignificant as to inflict welfare losses on farming households.

Rural non-agricultural households with high education also benefit from recycling environmental tax revenues since the earnings to high education non-agricultural labour rises especially in simulation 2 (Table B5). Although these results are short-run responses, the change in relative price of land and of cash crops compared to staple crop, maize, could have negative consequences on food security of land constrained households in the long-run as households may be tempted to shift production to cash crops on their small landholdings (Tables B2 and B9).

Compared to simulations 1 and 2 when revenues are recycled, relaxation of the carbon constraint (simulation 3) actually unifies the distribution of welfare gains within rural and urban household categories, except that rural agricultural households with landholdings between 2 to 5 hectares still fair better than the rest. Also, a nonbinding carbon constraint is unfavourable to urban non-agricultural households with high education as these households have no way of diversifying their income sources to take advantage of the relaxed policy stance on carbon emissions (Table B1).

6.4.2 Real gross domestic product

Although some relatively capital intensive sectors such as construction and manufacturing would, as expected, reduce output, environmental tax and subsidy policies on fuelwood and fossil fuels lead to slight real GDP increases of between 0.2 percent when revenue neutrality constraint is nonbinding and 0.45 percent when environmental tax revenue is recycled and carbon constraint is relaxed (Table B6). Total domestic production falls consistently regardless of how the additional tax revenue is utilized by the regulator. However, output reductions are worse for most sectors when environmental policy is stringent and environmental revenues are recycled to reduce direct tax burdens on households (simulation 2, Table B4).

Agriculture, utilities (electricity and water) and manufacturing sectors have output gains regardless of how environmental revenues are utilized. Services sectors however benefit only in simulation 2 when environmental policy on carbon emissions and fuelwood is stringent

(Table B6). These results support expectations that environmental taxes on fuelwood and fossil fuels would benefit labour intensive sectors, particularly those that hire labour with low to medium education levels. The gains in agriculture and manufacturing sectors are slightly improved when environmental revenues are distributed to households because households spend some on the transfers on products from these sectors. This is particularly evident for tea and coffee, tobacco, forestry, fisheries, meat and dairy products for agriculture and for services, banking and insurance, and distribution services for agriculture and other (unclassified) distribution services. Relaxation of the carbon constraint (simulation 3) is also particularly beneficial to most sectors, although the distribution of output gains or losses across all sectors is virtually similar with or without revenue neutrality (Table B4).

6.4.3 Government revenue

Government revenue is at its peak when a stringent environmental policy is implemented (simulation 2) and in particular when no revenue-neutral constraint is imposed on the fiscal system (Table B7). Simulation 2 also yields the highest net environmental tax revenue made up of tax revenue on fuelwood and carbon emissions, and subsidy on hydropower. Government revenue generally increases as environmental tax rates are increased because other taxable components are also increasing with the implementation of environmental policy. In particular, increases in factor income, exports and domestic output of some key taxable sectors bolster tax revenue (Tables B7 and B8).

When total non-environmental tax revenues are endogenously determined while additional environmental revenues are distributed to households, yield from pre-existing taxes would increase by at most 3.2percent. In simulations 1 and 2, environmental tax yields are consistently higher at higher tax rates since some distortions caused by pre-existing taxes are reduced by redistributing revenues to households (Tables B7 and B8). Hence, placing a ceiling on pre-existing tax revenues while environmental taxes are being recycled would be inefficient from both the revenue point of view and economic considerations. In particular, the results show that GDP is slightly higher when pre-existing tax yields are flexible, implying that the efficiency losses from the interaction between environmental taxes and pre-existing taxes could be significant when a ceiling is placed on pre-existing taxes. This assertion was verified by introducing an absolute revenue ceiling on pre-existing taxes. The result, not included in the appendix, was a total reduction in domestic output of at most 1.5 percent which is comparable to the loss in revenue when the carbon constraint is relaxed.

6.4.4 Savings and investment

Total household savings generally fall in all simulations regardless of how additional environmental policy revenues are utilized (Table B3). The impact of specific households however depends on the impact of policies on factor incomes and on prices of consumer goods. When environmental tax revenues are not recycled, all households except rural agricultural households with large land holdings, rural non-agricultural households with high education, and all other non-agricultural households with low and medium education would have higher factor incomes. Among these, households that had positive savings in benchmark scenario would correspondingly increase or reduce savings, with the greatest reduction in saving incurred by urban non-agricultural households with high education (Tables B2, B3 and B5). When revenue-neutral measures are introduced, the positive increase in savings of rural households is more pronounced while urban households would have zero or negative increase in saving. However, urban agricultural households would benefit from recycled environmental revenues as savings increase by up to 1.5percent. The presence of a nonbinding carbon emission constraint leads to marginal increase in saving for all household categories. However, there is no conclusive evidence to suggest that savings improve when the carbon constraint is relaxed conjointly with revenue-neutral considerations.

In all simulations, foreign saving is held constant while the exchange rate, and foreign aid flows are allowed to vary to bring about equilibrium of balance of payments. Savings by government decline in all simulations particularly with revenue neutrality (Table B3). Since net national saving falls in all simulations regardless of whether environmental taxes are recycled or not, investment demand also declines. However, the change in investment demand is significantly higher under revenue-neutral regimes, reflecting that a significant portion of investment in the economy is by government. Hence, if the additional revenue was to support investment in environmental protection, it would be in the interest of the regulator to allocate the additional environmental revenue to the pool of government resources.

6.4.5 Capital-intensive versus labour-intensive sectors

For simplicity, labour intensive (capital intensive) sector is defined to mean a sector whose main value added component is labour (capital). To assess the impact of environmental policy on labour intensive and capital intensive sectors, we compare the change in output averaged over simulations 1 and 2 for revenue-neutral and non-neutral scenarios, respectively.

In benchmark scenario, labour intensive sectors contribute MKW 50, 448.1 million (53percent) to domestic output while capital intensive sectors produce MKW 43, 906.6 million (47percent) (Table B18). The entire economy has overall output gain when environmental policy is imposed. Although there are gains and losses for both labour intensive and capital intensive sectors, on aggregate, it is capital intensive sectors that have output gains while labour intensive sectors lose out. Hence, environmental policy is favourable to capital intensive sectors in that gains in capital intensive sectors more than offset the loss in labour intensive sectors, resulting in overall output improvement for the entire economy. However, the loss in output from labour intensive sectors is very low compared to both benchmark and policy induced levels of output suggesting that any damage to employment would be very low.

For agricultural sectors, fisheries and other crops are the major sources of growth but most of the growth in output in the economy is from services sectors. In particular, environmental policy is favourable for telecommunications and transport, oil distribution, and banking and insurance. The only labour intensive manufacturing sector that benefits from environmental policy is the activity of manufacturing non-metallic mineral products.

For capital intensive sectors, manufacturing of plant and machinery almost doubles its output when environmental policy is implemented. Manufacturing of rubber products, and textiles and wearing apparel are other capital intensive beneficiaries of environmental policy (Table B 18). Construction, large-scale sugar growing, and manufacturing of soaps, detergents and toiletries, beverages and tobacco, and paper and printing are capital intensive sectors that lose out when environmental policy raises production costs for carbon-intensive energy users regardless of how additional revenues are distributed in the economy.

6.4.6 International trade and competitiveness

Under a flexible exchange rate regime and fixed foreign savings, recycling of environmental revenues leads to a fall in foreign aid flows as the Malawi Kwacha appreciates in value. All other things being equal, the overall demand for exports is likely to increase. This is attained in the main agricultural export sectors of tobacco, tea and sugar production. Total exports rise by between 0.6 percent and 2 percent in simulations 1 and 2, regardless of how additional environmental revenues are utilized (Table B19). Most of the gains in exports are in non-traditional sectors of manufacturing of plant and machinery, wood products, chemicals, fabricated metal products, textiles and wearing apparel, and business services. Except for fabricated metal products, these sectors are generally less carbon-intensive, and therefore do not face environmental policy constraints in production. Carbon-intensive sectors such as manufacturing of soaps, detergents and toiletries, and of beverages and tobacco face the highest reduction in exports in all simulations, regardless of how additional environmental revenues are utilized.

The increase in benchmark trade deficit from carbon-intensive sectors is significant considering that some imports increase by more than 100percent. Nevertheless, environmental policy generally improves international competitiveness as the major importing sectors such as manufactures of chemicals, plant and machinery, and services of telecommunication and transport consistently reduce imports. This is particularly significant for chemicals and plant and machinery which experience a surge in demand for its exports. Overall, trade deficits increase for carbon-intensive sectors but as indicated above, gains are significant in traditional and non-traditional export sectors. Relaxing the carbon constraint is also particularly beneficial to exporting sectors in both revenue-neutral and non revenue-neutral scenarios.

6.5 Environmental implications of the policy scenarios

6.5.1 The first and second dividends of environmental policy

The environmental policy is implemented to reduce carbon emission from fossil fuels and to reduce pressure on forests from fuelwood use by production activities. The exogenous reductions in carbon emissions from fossil fuels (oil and coal) and total use of fuelwood by production activities are the first and second dividends of the policy. There is an induced reduction of carbon emissions by 6 percent and 12 percent in simulations 1 and 2, respectively. There is also reduced fuelwood demand by between 1.3 percent and 1.9 percent with revenue neutrality and between 1.6 percent and 2.2 percent with non revenue-neutral policy stance in simulations 1 and 2, respectively (Table B10).

Tax revenues from fuelwood range from 6.8 to 12.6 million Kwacha when environmental revenues are not recycled to reduce distortions in the fiscal system. Under non-neutral revenue conditions, taxes on emissions from oil and coal yield between 555.7 and 649.3 million Kwacha when the carbon constraint is in place and nothing when the carbon constraint is nonbinding. In contrast, increasing hydropower demand would require subsidies ranging from 265.6 to 271.5 million Kwacha. In particular, a 12.5 percent subsidy on hydroelectricity has the effect of increasing demand for hydroelectricity by 4.9 percent to 7.6 percent depending on other environmental taxes and whether environmental revenues are distributed to households or not (Tables B8 and B10).

Imposing revenue-neutral conditions slightly raises tax revenues from fuelwood and carbon emissions. Similarly, total subsidies for increasing hydropower demand also decline since inefficiencies associated with tax interactions when revenues are not recycled are reduced. This in turn increases total environmental revenues from 293.6 million Kwacha in simulation 1 with no revenue-neutral constraint to a maximum of 408 million Kwacha when a revenue-neutral constraint is in place in simulation 2 (Table B10). In addition to lowering tax interactions when additional environmental revenues are distributed to households, total environmental tax revenue increases because marginal costs for abating carbon emissions are strictly increasing as abatement targets are increased. This is consistent with expectations that as environmental policy becomes stringent, the adjustment costs for different sectors of the economy must increase proportionate to levels of energy demand.

Sectoral responses to changes in marginal tax rates on fuelwood and marginal abatement cost (MAC) of carbon are not radically altered by recycling environmental revenue. However, carbon-intensive manufacturing activities have the largest reduction of carbon emission relative to benchmark emissions and the proportions are not altered by recycling of environmental revenues while for construction, recycling of revenues significantly increases rate of reduction in emissions (Table B12). In manufacturing, the activity of manufacturing of soap, detergents and toiletries has the highest single reduction in carbon emissions followed by distilling of spirits and manufacturing of malt liquor and soft drinks.

Although some manufacturing activities such as plant and machinery, and rubber products considerably increase emissions in all simulations, these sectors are insignificant since they contribute about 2.8 percent to total emissions in the benchmark scenario. In contrast, two manufacturing sectors (manufacturing of soap, detergents and toiletries, and manufacturing of distilled spirits, malt liquor and soft drinks) that contribute 77 percent of total emissions have a substantial reduction of emissions averaging 1.85 to 19.9 percent in simulations 1 and 2, respectively (Table B13). Thus, overall, marginal increases in emissions from small sectors are offset by large reductions in emissions by sectors that are carbon-intensive in their energy demands.

Regardless of whether revenues are recycled or not, the manufacturing sector also has the largest reduction of fuelwood use relative to benchmark demand (Table B14). In particular, processing of sugar, manufacturing of soap, detergents and toiletries and activity of distilling of spirits and manufacturing of malt liquor and soft drinks are important sectors as they have the greatest response in reducing fuelwood use. These sectors together account for 72.4 percent of fuelwood demanded in the benchmark scenario. However, growing of tobacco and tea, and activity of fabricating metal products would have a negative impact as these activities slightly increase fuelwood demand considering that together they account for 20 percent of fuelwood demand in benchmark scenario.

Tobacco growing which accounts for 14 percent of demand for fuelwood in benchmark case would increase fuelwood demand by about 0.2 percent in simulations 1 and 2. Tea growing which in benchmark accounts for 5.8 percent of fuelwood demand increases fuelwood demand by 0.4 percent in simulations 1 and 2 (Table B16). This result is consistent with findings in chapter 5 that fuelwood has limited substitution options with other fuels in the energy aggregate when carbon-intensive fuels are also taxed. In particular, tobacco and sugar growing (0.91) and tea, coffee and macadamia growing (1.25) would substitute fuelwood for hydroelectricity at a sluggish rate (chapter 5, Table 13). With taxes, total demand for fuelwood falls by between 1.3 percent and 2.2 percent since proportional increase in fuelwood demand is less than cumulative reductions in demand in the entire economy (Table B16).

Comparing simulation 3 when the carbon constraint is relaxed with a modest carbon constraint of 6 percent reduction in emissions (simulation 1), it is noted that for similar subsidy rates on hydroelectricity, an additional 3.7 megatons of carbon would be emitted over and above the benchmark total when environmental tax revenues are pooled with other government resources while 0.4 megatons of carbon would be abated by introducing revenue neutrality in the fiscal system. These additional emissions represent 18 percent of carbon abated when environmental revenues are pooled with other tax revenues or 16 percent of the carbon abated when additional tax revenues are distributed to households (Table B11). Simulation 3 also shows that emissions can increase at zero cost to producers if other environmental revenues are pooled with government resources or with a 0.36 million Kwacha tax per megaton of carbon if environmental tax revenues are distributed to households.

Doubling the carbon constraint (simulation 2) also doubles the difference between tolerable emissions when the carbon constraint is nonbinding and what can be abated when the carbon constraint is in place. However, there are sectoral differences in emission reductions, with a few key emitters reducing their benchmark emissions by more than the carbon constraint (Table B13). This suggests that it would be possible to reduce energy-related emissions without imposing a strict constraint on initial emissions. This is obviously the case for activities of growing sugar, paper manufacturing and printing, and construction, as these sectors actually reduce their benchmark emissions by an average of 2.9 percent when the carbon constraint is nonbinding. Similarly, the activity of manufacturing of soap, detergents and toiletries also reduces emissions by more than the carbon constraint in simulations 1 and 2.

These results are significant since the sectors that reduce carbon emissions when a carbon constraint is nonbinding collectively account for 43.2 percent of total emissions in benchmark scenario. Thus, it is not absolutely necessary to tax fuelwood and carbon emissions for environmental policy to effectively reduce carbon emissions and deforestation in the economy. This is important for Malawi because oil is a heavily taxed imported commodity that has knock-on effects on prices of many other commodities.

The environmental policy simulations also show that there would be direct emission reductions (or increments) and indirect emission reductions calculated from forgone combustion of biomass. The highest net emission reduction is 44.4 megatons of carbon when a stringent environmental policy is in place while the lowest net emission reduction is achieved when a modest direct reduction of carbon emission from oil and coal is implemented (Table B11). Further carbon abatement would be possible if biomass not used as fuel could be maintained in standing forest which in turn sequestrates atmospheric carbon. However, carbon sequestration gains in environmental quality are not captured by this study[10].

6.5.2 The third dividend of environmental policy

The third dividend is obtained when introduction of environmental taxes result in real GDP at least equal to benchmark value. This was achieved even when environmental tax revenues are not recycled to reduce direct taxes on households (Table B6). Also, a revenue-neutral environmental policy leads to additional gain to the economy in that aggregate household welfare improves. Further, the resulting welfare distribution among households is pro-poor since all rural agricultural households are welfare winners (Table B1).

6.5.3 The optimal energy mix

The optimal energy mix for Malawi is that set of fuels that yields maximum reduction in net carbon emissions from fossil fuels and minimizes total fuelwood demand by production activities at low cost to the economy. At equilibrium, the economy would use 2 percent less fuelwood costing 12.6 million Kwacha in excise taxes while carbon emissions would be reduced by 12 percent after imposing 2.18 million Kwacha tax per megaton of carbon emitted (Tables B8 and B10). This would be optimal if the environmental revenues are recycled to households and hydropower is subsidized by 12.5 percent, leading to a total subsidy expenditure of 264.2 million Kwacha and a 5.5 percent increase in hydropower demand[11].

Apart from abating a total of 44.4 megatons of carbon, the optimal energy mix would result in a direct reduction of fuelwood demand by 6.4 megatons, and net environmental revenue of 408 million Kwacha (0.8 percent of benchmark GDP) (Tables B8, B11 and B16). Excluding the subsidy on hydroelectricity, taxes on fuelwood and carbon emissions from fossil fuels are

[10] The sequestration rate used in Ecological Footprint calculations of the Living Planet Report of 2004 is based on an estimate of how much human-induced carbon emissions the world's forests can currently remove from the atmosphere and retain. It is estimated for instance that one global hectare can absorb the CO_2 released from consuming 1,450 litres of gasoline per year (Loh and Wackernagel, 2004).

[11] The Btu equivalent of hydroelectricity net demand is estimated by a flexible Cobb-Douglas structure specified in chapter 4. The same applies to fuelwood demand and net carbon emissions by production activities.

equivalent to 1.3 percent of benchmark GDP. This is significantly close to the annual growth rate of the economy's energy intensity per dollar GDP of 2.5 percent (IEA, 2003). As discussed above, recycling of environmental revenues only ensures that household welfare is at least equal to benchmark welfare and thus improves gains in other aspects of the economy.

6.6 Summary and conclusions

The impacts of tax and subsidy induced shifts from fuelwood and fossil fuels to hydroelectricity were analysed in terms of economic and environmental outcomes. In general, unit taxes on fuelwood and carbon emissions from oil and coal will improve the environment by directly reducing energy-related GHG emissions and relieving pressure on forests. The results also highlight the fact that taxes or subsidies are not the only solution to the twin problem of energy-related emission of greenhouse gases and deforestation in developing countries. In particular, Malawi could increase emissions from coal and oil as long as net carbon emissions are reduced by implementing an offsetting clean energy strategy such as increasing demand of hydroelectricity by production activities as well as maintaining standing biomass in forests to sequestrate carbon.

The direct cutback of emissions and industrial fuelwood use were counted as two dividends of environmental policy. Overtime, these could translate into a cleaner environment and less deforestation linked to energy use by production activities. Maintaining or improving benchmark value of gross domestic product was counted as a third dividend. The third dividend was obtained even without imposing revenue-neutral constraints on environmental policy. Thus, for Malawi, environmental taxes need not be revenue-neutral for a triple dividend to be obtained. However, revenue-neutral conditions are important when household welfare and distribution impacts are taken into account.

Although the general equilibrium results in this chapter represent short-run responses only, a number of medium to long-term inferences can be drawn. The long-run impact of environmental policy would depend on environmental and economic outcomes. First, capital intensive sectors such as manufacturing are expected to invest in more energy-efficient capital in order to counteract the cost of energy taxes. The short-run response indicates that labour intensive sectors such as services are going to lose from implementation of the energy tax. However, since the aggregate output loss by labour intensive sectors is insignificant relative to aggregate contribution to benchmark output by labour intensive and capital intensive sectors, respectively, it is likely that in the long-run any losses in employment would be minimal while energy-efficient capitalisation takes hold. This is consistent with conclusion of the previous chapter on long-run employment impacts of environmental taxes.

Second, the direct cost of energy demand on the environment as measured by the social cost of carbon emissions and fuelwood use by production activities was not significantly different from the moderate estimate of social cost of deforestation quoted in chapter 5. These general equilibrium results are important since in the absence of estimates of damages of secondary impacts of carbon emissions and deforestation, the optimal energy tax corresponds to the annual growth in economy’s energy intensity. Thus, if short to medium term impacts are important as is the case in Malawi where data on secondary damages are unavailable, it would be more efficient to target growth in intensities of use of certain fuels that are contributing to the economy’s burden on the environment.

Third, sectors that are heavily affected by the tax on fuelwood such as growing of sugar, manufacturing of soap, detergents and toiletries and beverages and tobacco could benefit from a policy that offers tax rebates on fuelwood sourced from own forest reserves. This would complement the existing but largely ineffective policy that requires agricultural estates to devote 10 percent of their land to tree crops (Hyde and Seve, 1993). Similarly, forests owned and managed by production activities could be used to assess carbon rebates a sector should be entitled to and the rebates could be assigned according to carbon sequestration potentials per hectare of forests owned.

CHAPTER 7: SUMMARY, CONCLUSIONS AND POLICY IMPLICATIONS

7.1 Summary

This study evaluates the implications of voluntary reduction in energy-related emissions for the environment and economic welfare in Malawi. It identifies an energy base consisting mainly biomass (fuelwood and charcoal) and fossil fuels as a threat to sustainable development because of its related environmental pressures. Although Malawi's total GHG emissions are negligible even by sub-Saharan Africa averages, the problems of deforestation and loss of forest cover due to industrial fuelwood use are quite significant. This study is unique in that it suggests solutions to greenhouse gas emissions within the economic development agenda for Malawi. The results prove that developing countries such as Malawi could achieve better economic and environmental outcomes by implementing policies that address not just efficiency problems in the energy sector but also environmental concerns.

This is the first study to analyse the economywide impacts of shifting the energy mix from biomass to modern fuel sources in Malawi. The study has policy relevance for GHG mitigation, forestry management and for efficiency of the energy sector. In terms of methodological contribution, the study complements partial equilibrium results with conclusions drawn from a CGE framework. In particular, an energy sector model consisting interfuel substitution model and an aggregate energy and non-energy input demand system that incorporates short-run and long-run structural adjustment parameters is specified. The energy sector results are used in simulations to assess partial equilibrium impacts of fiscal policy regimes that taxes biomass and carbon-intensive fuels while subsidizing hydroelectricity. The study also evaluates general equilibrium impacts of reducing fossil and biomass fuel use by production activities while investing in more hydropower. The general equilibrium results are specifically used to determine the optimal fiscal policy regime and thereby the optimal energy mix for the economy. This study is therefore a direct contribution to the literature on environmental CGEs in sub-Saharan Africa.

The main result of this study is that carbon emissions and forest resource depletion due to energy use, respectively, can be reduced by imposing environmental taxes aimed at inducing a shift from biomass and fossil fuels to hydroelectricity. More significantly, there are at least three dividends from inducing a shift in the energy mix of the economy in that the economy can attain GDP at least equal to the value before imposition of the environmental taxes besides reducing carbon emissions and deforestation. Further, redistributing the environmental revenues to reduce direct taxes on households could lead to better income distribution since low income (agricultural) households benefit more than high income (non-agricultural) households. Thus, depending on how the additional revenues are utilized by government, environmental taxes could complement poverty reduction goals.

The general equilibrium conclusions are consistent with partial equilibrium estimation results and simulations. Since the energy sector model reveals strong substitution possibilities among fuels in the energy aggregate and between energy and non-energy aggregate inputs, economic incentives could be used to induce firms to shift from fossil fuels and fuelwood to environmentally friendly energy sources such as hydroelectricity. In particular, the partial equilibrium policy simulations show that forest resource conservation could be enhanced by levying a positive tax on coal, zero tax on fuelwood and subsidizing hydroelectricity while the greatest reduction in carbon emissions could be achieved by positively taxing both fuelwood and coal. In addition, the aggregate energy and non-energy input demand system reveals that energy saving policies that favour capital intensive over labour intensive production could lead to lower energy use per unit of output since firms in Malawi adjust energy-capital input ratios faster than labour-energy ratios by about 10 percentage points.

Policy inferences from the energy sector model simulations are, however deemed inconclusive as they entail negative environmental and economic tradeoffs. Specifically, existence of substitution possibilities among fuels in the energy aggregate imply that tax induced differences in relative prices of fossil fuels and fuelwood could trigger either more use of fuelwood and hence deforestation or more use of fossil fuels and hence increased carbon emissions. Employment effects from energy conservation could also be significant in the long-run because of the slow rate at which firms adjust labour-energy input ratio compared to capital-energy input ratio. Hence, a policy that induces energy-efficient capitalisation by production activities could eventually impact negatively on labour employment although environmental benefits such as lower carbon emissions and deforestation per unit of output could be considerable.

Taking into consideration the inconclusive policy implications from the energy sector model, general equilibrium analysis was used to evaluate distributional costs and benefits of a policy that taxes fossil and biomass fuels while subsidizing hydropower. The CGE model establishes that taxes on fossil and biomass fuels would not impose undue costs to the economy, and that employment losses could be minimal regardless of how additional environmental revenues are utilized by the government. Ultimately, it is the distributional effect on factor incomes that matter since welfare for the representative individual improves in revenue-neutral scenarios. Thus, apart from improving the environment, environmental taxes would not reduce the economy's output (GDP) and could be welfare augmenting if the environmental tax revenues are redistributed to reduce direct taxes on households.

The study also finds credible support for key partial equilibrium analysis based conclusions. For instance, the partial equilibrium implication that capital intensive sectors could contribute to lowering energy intensities in production is confirmed by general equilibrium output responses of capital intensive sectors. Capital intensive sectors reduce demand for some fuels to minimize costs of producing a given level of output or reduce output when adjusting to extra energy costs associated with taxes on carbon emissions and fuelwood. However, a carbon tax policy might be a knife-edge since a lenient policy stance on emissions could result in reversal of output gains in capital intensive sectors since the tax leads to higher factor prices arising from excess demand for inputs in other sectors of the economy. Thus, only when carbon emission reduction targets are large would taxes on fossil fuels and fuelwood and subsidies on hydroelectricity have positive impacts on capital intensive sectors sufficient to offset negative impacts on labour intensive sectors.

The study also highlights the fact that environmental policy may be beneficial for both traditional and non-traditional exporting sectors. In particular, there are clear gains in all major export crops, although on aggregate for the whole economy's trade balance deteriorates with imposition of strict environmental policy. On the other hand, relaxation of the carbon constraint leads to improvement in competitiveness as the trade deficit narrows. This result is particularly important in that in the absence of policy coordination, domestic sectors may be overly disadvantaged by environmental policy while dirty consumer and producer goods are imported at zero environmental surcharges.

The general equilibrium model also highlights policy alternatives to taxation that can be pursued to achieve the dual goal of reducing deforestation and carbon emissions associated with energy use. One alternative is a carbon rebate system based on biomass left in standing forests. Currently, large agricultural estates in Malawi are required by law to devote 10 percent of their land to tree crops. However, the system does not reward farmers who devote substantially more land to tree crops nor does it effectively sanction those that fail to adhere to the law. This study suggests that the law should evolve into a rebate system whereby production activities can exchange their carbon emissions from fossil fuels with carbon that can be sequestrated by biomass in standing forests owned or maintained by the producers. In addition, a tradable permit system can be developed based on the rebate system to encourage those that have excess land to plant more trees and increase their emission rights.

7.2 Conclusion and policy implications

There are persuasive economic conditions for Malawi to introduce environmental taxes on fuelwood and carbon-intensive fossil fuels. This would not only reduce environmental pressures, but would also improve efficiency in other energy sub-sectors such as hydroelectricity. This is crucial because with economic growth and rising energy demands, cumulative GHG emissions from developing countries will continue rising faster than those from industrialized countries implying that convergence with developed regions in terms of cumulative contributions to GHGs may not be far off. Thus, Malawi must strategically position itself in international agreements for reducing environmental pressures while pursuing higher goals of economic growth and poverty reduction.[12]

Most developing countries consider environmental taxes as undesirable for compromising economic growth and other social goals. However, as shown in this study, environmental

[12] The climate change negotiations in Copenhagen, Denmark in December 2009 (COP 15) revealed strong considerations by some influential developed countries for tangible commitments from developing countries. It is thus envisaged that the next round of negotiations in Canada in December 2010 may focus on what developing countries can realistically do in order to have a global climate change agreement after Kyoto. This may include adaptation of emission targets for larger and fast growing developing countries like China and India, and financing arrangements for climate change adaptation and mitigation for other developing countries, including Malawi.

taxes can be welfare improving depending on initial conditions including efficiency of existing taxes, size of inefficiency the new tax is correcting and how government utilizes the additional tax revenue. The direct environmental benefits estimated by this study are only a small proportion of total benefits since reduced deforestation has significant positive impacts on ecosystem system functions such as conserving biodiversity, watershed protection, and soil conservation. Forests are also important in the global context of absorbing carbon from the atmosphere and mitigating the impact of climate change. Malawi should therefore develop its forestry to rip benefits from carbon trading schemes that may come with future global agreements on climate change. The economy therefore stands to benefit substantially more from a policy that induces a shift from biomass fuels to avert deforestation in several ways.

In general, it is expected that over time, biomass energy use and greenhouse gas emissions will be influenced by costs imposed on producers and on consumers by environmental policy. The direct environmental benefits to the economy will depend on short-run and long-run elasticities of demand for taxable intermediate inputs especially fuelwood and fossil fuel. For primary resource extractions, the impact of an environmental tax will depend on the scale of production that drives resource use. In addition, the impact of environmental taxes on households will be felt through prices of taxed commodities and through income effects arising from energy and non-energy input substitution in production.

The estimate of direct environmental cost associated with the use of fuelwood and fossil fuels is not significantly different from the moderate estimate of social cost of deforestation in the Malawi NEAP. This is significant because in the absence of estimates of damages of secondary impacts of both carbon emissions and deforestation, the optimal energy tax as inferred from the general equilibrium model corresponds to the annual growth rate in economy's energy intensity. Since short-run to medium term environmental impacts are critical in the case of Malawi where data on secondary damages are unavailable, it would be prudent to target growth in intensities of use of fuels that contribute to the economy's footprint on the environment.

Countries like Malawi where domestic production is low compared to domestic absorption face both financial problems from balance of payments, and environmental costs of disposal of materials from traded goods. Where there are negative externalities in consumption but production takes place under conditions of perfect competition, importing countries are expected in theory to develop strategic trade policies that address the externality within their jurisdiction. If the small country assumption is valid, there are a few significant process instances per industry, i.e., production stages with intense environmental interventions, thereby allowing time and location dependent assessment of environmental impacts in relation to the entire sector or economic system. In particular, the manufacturing of soaps, toiletries and detergents, and the activity of distilling malt liquor and manufacturing of soft drinks are key sectors for both industrial fuelwood use linked to deforestation and carbon emissions from fossil fuels. It is therefore feasible for the environmental regulator to collect pollution and biomass fuel use information on each firm, and apply appropriate environmental policy instrument especially on firms that produce tradable output.

7.3 Study limitations and recommendations for further study

The limitations of this study are endemic to most if not all static environmental CGE models. The first major limitation is that in the calibration of the model, elasticities for all inputs are calculated from equilibrium values in the SAM. As a result, our simulations only give an indication of the direction and size of the effects of policy changes. However, the results are fairly robust to changes in the range of values for the proposed change in environmental taxes. The second limitation is that environmental feedbacks are not explicitly modelled in production and utility functions and so dynamic effects are ignored.

The implication of the second limitation is that the model may have overestimated the cost of environmental policy to the economy or equivalently underestimated environmental benefits because technology improvements or changes in consumer tastes were not considered over the simulation period. This is also compounded by the fact that data limitations does not permit the CGE model to adequately represent substitution possibilities among fuels in the energy aggregate, and between energy and non-energy aggregates in production. The efficiency loss of the model in terms of accuracy and reliability of results is however mitigated by the assumption that the estimated environmental externalities have a small positive elasticity of substitution with output. Hence, pure output losses due to model specification error are minimized, and thus the results are much closer to reality.

Since energy driven environmental interventions are important, this study could be improved by modelling at the highest level of detail all energy products in the CGE. This would require disaggregated SAM data for all energy products (fuelwood, oil, coal and hydroelectricity) to improve validity of results since as Thompson (2006) argued, substitution involving an aggregate is not necessarily a weighted or other average of the disaggregated inputs. In particular, to measure the overall economic impacts of changes in the energy sector, the impacts are heavily dependent on interfuel substitution as well as the rate at which firms adjust their non-energy and energy input ratios with respect to labour and capital. These aspects could be modelled more vividly with additional data.

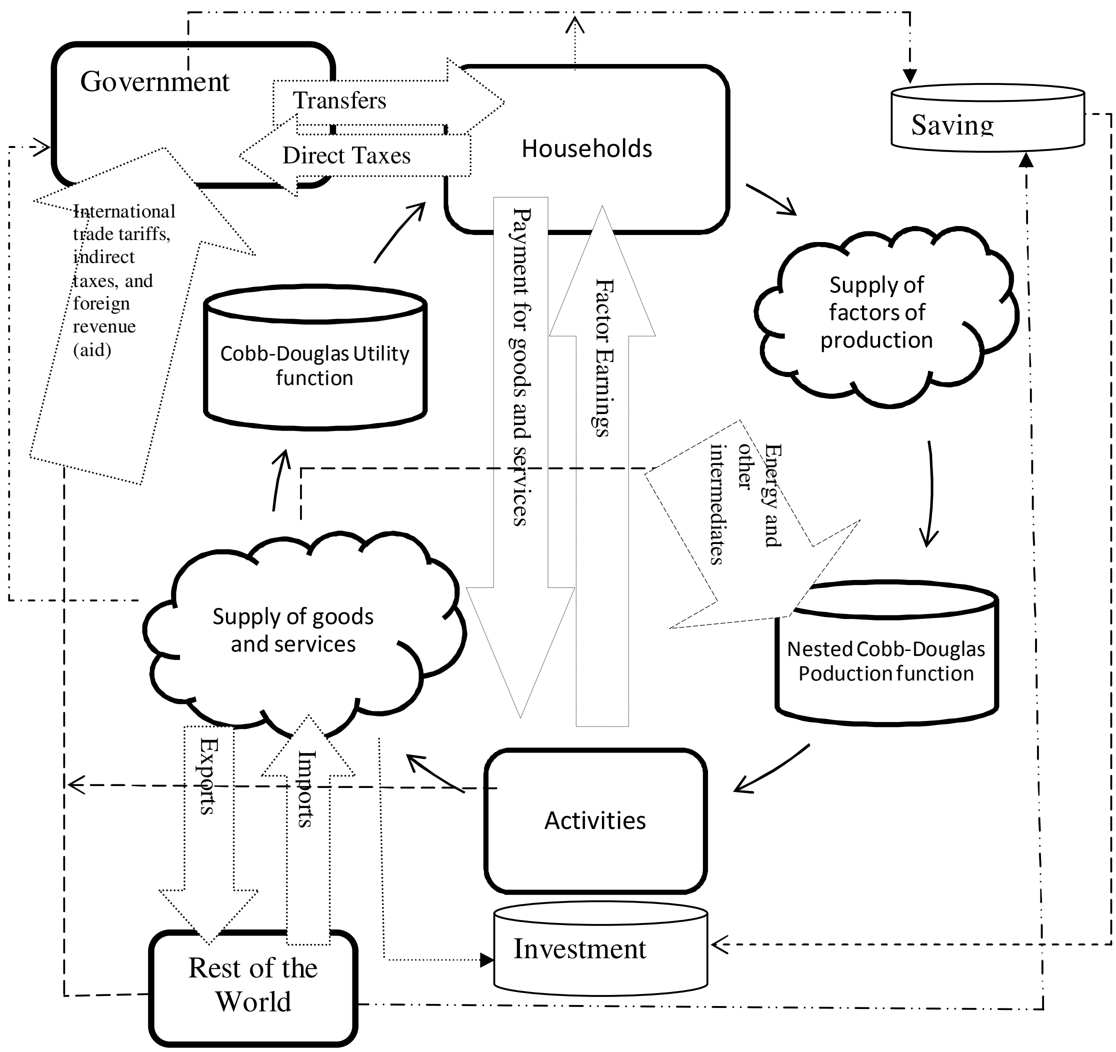
Dynamic elements of the partial equilibrium model suggest that the static CGE is only an approximation of how firms and households may react to environmental policy. The dynamic adjustment processes by labour intensive and capital intensive sectors are crucial and must be observed over a period long enough for firms to vary capital-labour ratios in the simulation. This requires more data, additional modelling (subroutines for dynamic elements), and more precision in assumptions of structure and calibration parameters. The dynamic CGE approach would also be more appropriate for analysing the implications of international agreements on GHG emissions to which Malawi is a party. In particular, it would be valuable to test the results of this study within the context of a new global climate change agreement (post Kyoto and Copenhagen) which may include emission targets for developing countries as well as financial arrangements for climate change adaptation and mitigation.

APPENDICES

APPENDIX A: ALGEBRAIC SPECIFICATION OF THE GENERAL EQUILIBRIUM MODEL

The general equilibrium model described below follows the logic of the circular flow of income in a small open economy. The algebraic specification of the transactions of production activities, households, government, and the rest of the world and are summarised in algebraic form below. The transactions are summarised in figure A1.

Figure A1: A schematic representation of the model



a) Household behaviour

Households have uniform Cobb-Douglas preferences that differ only in expenditure shares. The objective of each household h is to maximize utility U^h from the consumption of goods and services subject to resource constraint:

$$\max U^h(c) = \prod_{i=1}^{n} \mathrm{c}_{\mathrm{i}}^{\gamma_{\mathrm{ih}}} \quad s.t. \quad y^h = pc^h \qquad \text{A1}$$

Where $c = (c_1, c_2, \ldots, c_n)$ is a vector of goods and services, $p = (p_1, p_2, \ldots, p_n)$ is a goods prices corresponding to vector c, γ_{ih} is the share of commodity i in household $h's$ expenditure and y^h is household $h's$ consumption expenditure.

Household consumption expenditure depends on factor earnings, savings, transfers to the rest of the world, transfers from the government and direct taxes paid by the household. Factor earnings by household h, denoted y_h^F depend on initial endowment of factors of production,

$$y_h^F = \sum_f \left(r_f \times \iota_f^h \times SS^f\right) \qquad \text{A2}$$

Where r_f is the price of factor, is f, SS^f the total supply of factor f and ι_f^h is the share of household $h's$ endowment of factor f. Factor earnings are taxable and household $h's$ direct tax obligation is given as:

$$DTAX^h = \tau_h^d y_h^F \qquad \text{A3}$$

Where τ_h^d is the direct tax rate on household h.

Household saving are also a function of factor earnings, and exogenous transfers from government:

$$S^h = s_h \times \left(y_h^F + TR_h^G\right) \qquad \text{A4}$$

Where s_h is household $h's$ marginal propensity to save out of factor earnings and exogenous transfers from government, TR_h^G.

In Lofgren (2001), capital factor earnings were first distributed to enterprises and then transferred to households and the rest of the world. In this study, all capital earnings are transferred directly to households which then pass on the earnings to the rest of the world. For simplicity, household transfers to the rest of the world are fixed at the initial level and are thus treated as exogenous. As a consequence, household $h's$ disposable income is given as:

$$y_h^d = \left(1 - \tau_h^d - s_h\right) y_h^F + \left(1 - s_h\right) TR_h^G - BOP^h \qquad \text{A5}$$

Where BOP^h is household $h's$ transfers to the rest of the world.

b) Production activities and commodities

Production activities have nested Cobb-Douglas production technology for aggregating inputs at two levels, the energy aggregation stage and the output aggregation stage (equations 5.1 and 5.4 in the text). Government imposes indirect taxes on production activities on ad valorem basis and the tax obligation for sector j is calculated as follows:

$$CTAX_j = \tau_j^c \times p_j \times Q_j \qquad \text{A6}$$

Where τ_j^c is the tax rate on activity j and Q_j is gross output.

c) International trade

Malawi is a small open economy that cannot influence international market prices for its exports and imports. Thus, import and export prices in local currency are respectively a function of foreign prices and the exchange rate:

$$p_j^m = EXR \times P_j^{Wm} \qquad \text{A7}$$

$$p_j^x = EXR \times P_j^{Wx} \qquad \text{A8}$$

Where p_j^m and p_j^x are local currency prices of imports and exports, respectively, EXR is the exchange rate, P_j^{Wm} and P_j^{Wx} are, respectively, the exogenous import and export prices in foreign currency units.

Import demand and export supply functions are also a function of local currency prices and the exchange rate:

$$C_j^M = \overline{C}_j^M \times \left(\frac{p_j^m}{EXR} \right) \qquad \text{A9}$$

$$C_j^X = \overline{C}_j^X \left(\frac{EXR}{p_j^x} \right) \qquad \text{A10}$$

Where C_j^M and C_j^X are import demand and export supply values, respectively, while $\overline{C}_j^M$ and $\overline{C}_j^X$ are initial import demand and export supply values, respectively.

The other exchanges between the rest of the world and local institutions include foreign savings and foreign direct transfers to government. Thus, the balance of payments equation is specified as:

$$\sum_h BOP^h = \sum_j \left(C_j^X - C_j^M \right) + \left(S^F + EXR \times R^{FG} \right) \qquad \text{A11}$$

Where S^F and R^{FG} are foreign savings and foreign direct transfers to government, respectively.

d) Government

Government consumes goods and services in fixed proportion depending on indirect taxes, direct taxes, import tariffs, transfers from the rest of the world, government savings and government transfers to households.

$$G_j = \eta_j \times \left[\sum_j CTAX_j + \sum_j MTAX_j + \sum_h \left(DTAX^h - TRANS^h \right) + EXR \times R^{FG} - S^G \right] \qquad \text{A12}$$

Where G_j is government consumption of the j^{th} commodity, η_j is the share of the j^{th} commodity in government expenditure, S^G is government saving, and the import tariff on commodity j is given as:

$$MTAX_j = \tau_j^m \times p_j^m \times C_j^M \qquad \text{A13}$$

Where τ_j^m is import tariff rate on commodity j.

Government saving is a function of the marginal propensity to save out of the net revenue from taxes, foreign direct transfers and government transfers to households:

$$S^G = s_g \left[\sum_j \left(\tau_j^c \times p_j \times Q_j \right) + \sum_j \left(\tau_j^m \times p_j^m \times C_j^M \right) + \sum_h \left(\tau_h^d y_h^F - TRANS^h \right) + EXR \times R^{FG} \right] \qquad \text{A14}$$

Where s_g is the government's marginal propensity to save.

e) Investment behaviour

Investment for the j^{th} activity is a function of a fixed share of investment expenditure and supply of loanable funds which consists of household savings, government saving and foreign savings:

$$I_j = \omega_j \times \left[S^G + \sum_h S^h + \left(EXR \times R^{FG} \right) \right] \qquad \text{A15}$$

Where I_j and ω_j are investment demand and share of commodity j in investment expenditure, respectively.

f) Market clearing conditions

i. Goods market equilibrium

The goods market is in equilibrium when for each product, the sum of net domestic production and net imports are equal to the sum of household consumption demand, intermediate demand, investment demand and net exports:

$$p_j \left(1+\tau_j^c\right) \times Q_j = \sum_h C_j^h + I_j + G_j + \sum_i ID_{ji} + p_j^x C_j^X - p_j^m \left(1+\tau_j^m\right) C_j^M \qquad \text{A16}$$

Where ID_{ji} is intermediate demand for sector $j's$ output.

ii. Factor market equilibrium

Since production activities have constant returns to scale technology, implying that factors are paid their marginal products, demand for factor f is by sector j is given as:

$$Z_f^j = \frac{\alpha_f^j \times \left(p_j \times Q_j\right)}{r_f} \qquad \text{A17}$$

Where Z_f^j is the quantity of factor f and α_f^j is the Cobb-Douglas elasticity of output with respect to the factor.

It is assumed that households will supply more factors for higher factor prices, and that there is no unemployment (except voluntary unemployment). The economy is therefore at full employment and as such factor markets are in equilibrium when the sum of factor demands by production sectors is equal to the supply of factors by households:

$$\sum_{j} Z_{f}^{j} = SS^{f} \qquad \text{A18}$$

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APPENDIX B: GENERAL EQUILIBRIUM RESULTS

Table B 1: Change (%) in household utility

Household category	Benchmark Utility value	No revenue neutrality SIM 1	SIM 2	SIM 3	Reduced direct taxes SIM 1	SIM 2	SIM 3
Representative household (fictitious utility):	3787.7	-0.4	-1.1	1.0	1.0	0.7	1.1
Rural agriculture less than 0.5 ha landholding	343.9	-0.7	-1.2	0.9	1.1	0.8	1.0
Rural agriculture between 0.5 ha and 1.0 ha landholding	426.8	-0.9	-1.6	0.9	1.6	1.3	1.1
Rural agriculture between 1.0 ha and 2.0 ha landholding	500.5	-0.9	-1.5	0.8	1.1	0.7	1.0
Rural agriculture between 2.0 ha and 5.0 ha landholding	303.7	-0.8	-1.4	0.7	6.9	7.5	2.2
Rural agriculture more than 5.0 ha landholding	161.0	0.3	0.0	1.0	2.3	2.3	1.3
Rural non-agriculture no education	119.9	-0.3	-1.2	1.7	-0.4	-1.2	1.3
Rural non-agriculture low education	172.4	-0.4	-1.1	1.6	-0.5	-1.1	1.2
Rural non-agriculture medium education	336.0	-0.6	-1.1	0.8	-0.3	-0.8	0.7
Rural non-agriculture high education	61.3	-0.7	-0.7	-0.6	0.4	0.6	-0.3
Urban agriculture	209.2	0.2	-0.1	0.8	2.3	2.3	1.2
Urban non-agriculture no education	45.0	1.0	0.7	2.0	1.1	0.8	1.8
Urban non-agriculture low education	192.0	-0.3	-1.3	1.8	-0.8	-1.8	1.3
Urban non-agriculture medium education	388.9	0.0	-0.7	1.5	-0.3	-1.0	1.2
Urban non-agriculture high education	527.2	-0.2	-0.8	1.0	-0.5	-1.1	0.8

Note: **SIM1 = Simulation 1** **No revenue neutrality = When environmental revenues are not recycled**
SIM2 = Simulation 2 **Reduced direct taxes = When environmental tax revenues are used to reduce direct taxes**
SIM3 = Simulation 3

Table B 2: Changes (%) in relative factor prices

Relative Factor Prices	Benchmark	No revenue neutrality SIM 1	SIM 2	SIM 3	Reduced direct taxes SIM 1	SIM 2	SIM 3
No education agricultural labour	1	0.0	0.0	0.0	0.0	0.0	0.0
No education non-agricultural labour	1	1.0	1.0	1.3	0.1	0.0	1.0
Low education agricultural labour	1	0.0	0.0	0.0	0.0	0.0	0.0
Low education non-agricultural labour	1	0.8	0.7	1.3	-0.1	-0.2	1.0
Medium education agricultural labour	1	0.0	0.0	0.0	0.0	0.0	0.0
Medium education non-agricultural labour	1	0.2	0.4	0.0	-0.8	-0.7	-0.2
High education agricultural labour	1	0.0	0.0	0.0	0.0	0.0	0.0
High education non-agricultural labour	1	-0.7	-0.1	-1.7	-1.6	-1.2	-1.7
Small-scale land	1	-0.3	-0.2	-0.4	-0.3	-0.2	-0.4
Large-scale land	1	0.8	0.8	0.7	0.6	0.6	0.6
Capital agricultural small-scale	1	-0.2	-0.3	0.0	-0.1	-0.2	0.0
Capital agriculture large-scale	1	1.1	1.1	0.7	0.6	0.6	0.6
Capital non-agriculture	1	-0.4	-1.0	0.8	-1.5	-2.3	0.3

Table B 3: Changes (%) in savings and investment

	Benchmark Value (Million MKW)	No revenue neutrality SIM 1	SIM 2	SIM 3	Reduced direct taxes SIM 1	SIM 2	SIM 3
Government Saving	**2946.24**	-20.5	-14.9	-30.3	-27.9	-23.9	-30.2
Foreign Saving	**3964.00**	0.0	0.0	0.0	0.0	0.0	0.0
Household saving:	**351.66**	-0.2	-0.2	0.0	-0.1	-0.2	0.0
Rural agriculture more than 5.0 ha landholding	7.47	0.1	0.1	0.0	1.4	1.6	0.3
Rural non-agriculture high education	6.27	-0.6	0.0	-1.5	-0.3	0.3	-1.3
Urban agriculture	1.25	0.1	0.2	-0.1	1.5	1.9	0.3
Urban non-agriculture low education	32.87	-0.3	-0.8	0.8	-1.3	-2.0	0.4
Urban non-agriculture medium education	115.35	0.0	-0.3	0.5	-1.0	-1.4	0.2
Urban non-agriculture high education	188.45	-0.3	-0.5	0.0	-1.3	-1.6	-0.2
Investment	**7261.90**	-7.0	-5.0	-10.2	-9.7	-8.3	-10.2

Table B 4: Changes (%) in production by sector

		No revenue neutrality			Reduced direct taxes		
SECTOR	**Benchmark**	**Sim 1**	**Sim 2**	**Sim 3**	**Sim 1**	**Sim 2**	**Sim 3**
Maize (only small-scale)	5095.4	-0.9	-0.6	-1.2	-1.0	-0.7	-1.2
Tea and coffee	2308.6	5.2	5.1	5.3	5.3	5.2	5.2
Sugar growing (only large-scale)	260.9	-3.8	-2.2	-6.5	-5.6	-4.3	-6.5
Tobacco growing	8680.4	1.5	1.6	0.9	1.6	1.8	1.0
Fisheries	335.7	0.2	0.2	0.6	1.3	1.5	0.8
Livestock and poultry	1532.3	-2.9	-3.6	-1.1	-2.2	-2.8	-1.3
Forestry	662.2	1.4	1.8	0.5	0.8	1.2	0.5
Other crops	9078.6	0.3	0.1	0.6	0.6	0.5	0.7
Mining	707.9	-2.2	-3.8	3.6	-1.7	-3.1	2.7
Meat products	1653.0	-1.9	-3.0	0.6	-0.4	-1.2	0.5
Dairy products	528.1	1.1	1.3	0.8	2.1	2.4	1.1
Grain milling	7625.9	-0.3	-0.3	-0.2	0.7	0.9	0.0
Bakeries and confectioneries	423.9	-4.4	-5.6	0.5	-3.1	-4.0	-0.2
Sugar production	1601.8	-0.5	-0.7	0.6	1.1	1.2	0.6
Beverages and tobacco	3066.1	-7.3	-9.6	1.9	-5.5	-7.4	-0.1
Textiles and wearing apparel	2300.6	9.0	6.5	13.3	10.6	8.6	13.1
Wood products and furniture	1874.9	3.4	4.0	2.4	3.8	4.4	2.7
Paper and printing	1858.2	-7.2	-3.5	-13.5	-9.8	-6.6	-13.2
Chemicals	2159.1	14.1	17.5	8.9	12.2	15.3	9.6
Soaps, detergents and toiletries	1741.1	-32.1	-57.2	3.5	-32.7	-57.8	-2.2
Rubber products	448.8	44.5	42.1	53.6	47.5	46.1	53.2
Non-metallic mineral products	503.9	5.8	-2.7	33.0	3.7	-4.4	28.6
Fabricated metal products	1988.5	13.2	15.3	9.7	11.4	13.2	10.2
Plant and machinery	1173.4	116.0	111.3	123.8	116.5	112.1	124.0
Electricity and water	2862.1	3.8	4.8	2.6	2.4	3.1	2.6
Construction	3226.3	-8.6	-7.0	-11.1	-11.2	-10.1	-11.2
Oil distribution	583.8	3.6	3.7	3.8	3.8	3.9	3.8
Agricultural distribution	3331.6	4.4	4.5	3.8	4.6	4.8	3.9
Other distribution	8323.4	2.2	2.0	2.8	2.4	2.2	2.7
Hotels, bars, and restaurants	2774.6	-5.2	-5.2	-4.5	-5.0	-4.9	-4.7
Telecom and transportation	3417.9	-0.3	1.9	-4.8	-0.6	1.5	-4.0
Banking and insurance	2461.8	4.0	4.2	2.4	5.3	5.8	2.9
Business services	1396.3	-19.4	-12.8	-31.6	-25.8	-20.6	-30.9
Public services	6203.8	-1.6	-0.9	-2.8	-0.7	0.0	-2.3
Personal and social services	2164.0	-4.0	-3.0	-5.9	-5.0	-4.2	-5.7

Table B 5: Changes (%) in household disposable income

	Benchmark value (million MKW)	No revenue neutrality			Reduced direct taxes		
		SIM 1	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Representative household disposable income:	**46340.66**	**0.1**	**0.1**	**0.2**	**0.8**	**0.9**	**0.3**
Rural agriculture less than 0.5 ha landholding	3430.05	0.1	0.2	0.1	1.4	1.7	0.4
Rural agriculture between 0.5 ha and 1.0 ha landholding	3916.99	0.1	0.2	0.1	2.2	2.5	0.6
Rural agriculture between 1.0 ha and 2.0 ha landholding	4630.19	0.1	0.1	0.1	1.6	1.8	0.4
Rural agriculture between 2.0 ha and 5.0 ha landholding	3164.07	-0.1	-0.1	-0.1	7.2	8.3	1.6
Rural agriculture more than 5.0 ha landholding	1743.92	0.1	0.1	0.0	1.4	1.7	0.3
Rural non-agriculture no education	1360.13	0.6	0.6	0.8	0.1	0.0	0.7
Rural non-agriculture low education	1700.29	0.5	0.5	0.8	0.0	-0.2	0.6
Rural non-agriculture medium education	4114.42	0.1	0.3	0.0	-0.1	0.0	0.0
Rural non-agriculture high education	833.03	-0.6	0.0	-1.5	0.0	0.6	-1.2
Urban agriculture	3044.10	0.1	0.2	-0.1	1.6	1.9	0.3
Urban non-agriculture no education	700.44	0.7	0.7	0.8	0.1	0.0	0.7
Urban non-agriculture low education	2813.49	-0.3	-0.9	0.9	-1.4	-2.2	0.5
Urban non-agriculture medium education	6325.66	0.0	-0.3	0.5	-1.0	-1.4	0.2
Urban non-agriculture high education	8563.88	-0.3	-0.5	0.0	-1.3	-1.7	-0.2

Table B 6: Changes (%) in sectoral output and GDP

		No revenue neutrality			Reduced direct taxes		
	Benchmark Value (Million MKW)	SIM 1	SIM 2	SIM 3	SIM 1	SIM 2	SIM 3
Total domestic output	**94354.7**	**-0.3**	**-0.3**	**0.4**	**-0.8**	**-0.9**	**0.2**
Mining	707.9	0.7	0.7	0.6	0.8	0.9	0.6
Agriculture	27954.0	5.0	3.2	8.5	5.3	3.7	8.1
Manufacturing	28947.3	-2.2	-3.8	3.6	-1.7	-3.1	2.7
Services	30657.1	-0.5	0.2	-1.9	-0.6	0.1	-1.7
Utilities	2862.1	3.8	4.8	2.6	2.4	3.1	2.6
Construction	3226.3	-8.6	-7.0	-11.1	-11.2	-10.1	-11.2
Real GDP	**53676.09**	0.31	0.22	0.45	0.31	0.23	0.45

Table B 7: Changes (%) in non-environmental tax revenue and government consumption

		No revenue neutrality			Reduced direct taxes		
	Benchmark Value (Million MKW)	SIM 1	SIM 2	SIM 3	SIM 1	SIM 2	SIM 3
Government Revenue	8628.67	6.4	7.3	0.4	6.1	6.8	1.8
Government Consumption	7198.55	-19.8	-14.3	-29.3	-26.7	-22.6	-29.1

Table B 8: Net environmental revenue from environmental regulation

		No revenue neutrality			Reduced direct taxes		
	Benchmark Value (Million MKW)	SIM 1	SIM 2	SIM 3	SIM 1	SIM 2	SIM 3
Total net revenue from environmental regulation:	**0.00**	**293.6**	**390.3**	**-259.6**	**323.4**	**408.0**	**-128.8**
Total emission tax revenue	0.00	555.7	649.3	0.0	579.33	659.56	123.45
Total biomass tax revenue	0.00	6.8	12.6	0.0	6.86	12.60	12.81
Subsidy on hydroelectricity	0.00	-268.9	-271.5	-259.6	-262.78	-264.20	-265.02

Table B 9: Changes (%) in relative commodity prices

		No revenue neutrality			Reduced direct taxes		
Relative Commodity Prices	Benchmark	SIM 1	SIM 2	SIM 3	SIM 1	SIM 2	SIM 3
Maize (only small-scale)	1	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3
Tea and coffee	1	-1.1	-1.1	-1.3	-1.8	-1.9	-1.4
Sugar growing (only large-scale)	1	-2.2	-2.2	-2.3	-2.8	-2.9	-2.4
Tobacco growing	1	-0.2	-0.2	-0.2	-0.9	-1.0	-0.4
Fisheries	1	-0.1	0.0	-0.4	-0.3	-0.2	-0.4
Livestock and poultry	1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1
Forestry	1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Other crops	1	0.0	0.0	0.0	-0.1	-0.1	0.0
Mining	1	1.9	2.4	0.2	1.0	1.4	0.3
Meat products	1	0.3	0.4	-0.1	0.0	0.0	-0.1
Dairy products	1	-0.5	-0.7	-0.2	-1.4	-1.6	-0.5
Grain milling	1	-0.1	-0.1	-0.2	-0.4	-0.4	-0.3
Bakeries and confectioneries	1	1.5	1.8	-0.1	0.8	1.0	0.1
Sugar production	1	0.2	0.2	-0.2	-0.8	-0.9	-0.3
Beverages and tobacco	1	5.0	6.9	-1.8	4.3	5.8	-0.4
Textiles and wearing apparel	1	-1.5	-1.0	-2.4	-2.2	-1.8	-2.4
Wood products and furniture	1	-2.5	-2.5	-2.3	-3.1	-3.3	-2.5
Paper and printing	1	-0.5	-0.7	-0.4	-1.5	-1.8	-0.6
Chemicals	1	-2.6	-2.6	-2.8	-3.5	-3.6	-3.0
Soaps, detergents and toiletries	1	16.7	29.3	-1.9	16.7	29.0	1.0
Rubber products	1	-2.0	-1.9	-2.7	-2.9	-2.9	-2.8
Non-metallic mineral products	1	-0.5	1.2	-5.7	-1.0	0.4	-5.0
Fabricated metal products	1	-3.1	-3.2	-3.1	-4.0	-4.3	-3.3

		No revenue neutrality			Reduced direct taxes		
Relative Commodity Prices	Benchmark	SIM 1	SIM 2	SIM 3	SIM 1	SIM 2	SIM 3
Plant and machinery	1	-5.9	-6.1	-5.7	-6.7	-7.0	-5.9
Electricity and water	1	-2.7	-2.6	-3.1	-3.6	-3.6	-3.2
Construction	1	0.5	1.2	-1.2	-0.4	0.2	-1.1
Oil distribution	1	0.8	0.9	0.2	-0.2	-0.3	0.1
Agricultural distribution	1	0.0	0.0	0.1	-0.9	-1.1	-0.1
Other distribution	1	-0.5	-0.6	-0.1	-1.5	-1.7	-0.4
Hotels, bars, and restaurants	1	0.3	0.5	-0.4	-0.6	-0.5	-0.4
Telecom and transportation	1	-0.6	-0.7	-0.4	-1.6	-1.9	-0.7
Banking and insurance	1	-0.6	-0.6	-0.4	-1.6	-1.8	-0.7
Business services	1	-0.3	-0.3	-0.2	-1.3	-1.5	-0.4
Public services	1	-0.6	-0.4	-0.7	-1.5	-1.5	-0.8
Personal and social services	1	-0.1	0.0	-0.1	-1.0	-1.1	-0.3
Exchange rate	1	0.2	0.2	0.0	-0.5	-0.6	-0.1

Table B 10: Shadow prices of carbon emissions and biomass fuel, hydropower subsidy and equivalent percentage changes in carbon emissions, fuelwood demand and hydroelectricity demand

		No revenue neutrality			Reduced direct taxes		
	Benchmark values	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Tax on carbon emissions in Million MKW per Megaton	**0.00**	**1.72**	**2.15**	**0.00**	**1.79**	**2.18**	**0.36**
Tax (%) on fuelwood per Megaton	**0.00**	**13.0**	**24.0**	**0.0**	**13.0**	**24.0**	**24.0**
Subsidy (%) on hydropower per Mega-Btu	**0.00**	**-12.5**	**-12.5**	**-12.2**	**-12.5**	**-12.5**	**-12.5**
Total carbon emissions (Megatons)	343.52143	-6.0	-12.0	1.1	-6.0	-12.0	0.0
Total fuelwood demand (Megatons)	53.49462	-1.6	-2.2	0.1	-1.3	-1.9	-0.2
Total hydroelectricity demand (Mega-Btu)	173.61	5.6	4.9	7.5	6.0	5.5	7.3

Table B 11: Total environmental improvement in terms of carbon emissions abated

		No revenue neutrality			Reduced direct taxes		
Total Environmental Improvements:	**Benchmark Value in Megatons of Carbon**	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Direct carbon abatement	0.00	-20.6	-41.2	3.6	-20.6	-41.2	0.0
Biomass use forgone	0.00	-0.9	-1.2	0.1	-4.6	-6.4	-0.8
Total net carbon abated	0.00	-21.0	-41.8	3.7	-22.9	-44.4	-0.4

Table B 12: Changes (%) in aggregate industrial carbon emissions

		No revenue neutrality			Reduced direct taxes		
Industry	**Benchmark value in Megatons**	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Mining	7.90	-0.5	-0.8	0.8	-0.4	-0.7	0.6
Agriculture	1.53	0.1	0.1	0.1	0.2	0.2	0.1
Manufacturing	316.32	-6.5	-13.0	1.2	-6.5	-13.0	0.0
Services	7.88	0.9	1.0	0.9	1.0	1.0	0.9
Construction	9.89	-1.8	-1.4	-2.3	-2.4	-2.1	-2.4

Table B 13: Changes (%) in sectoral carbon emissions

		No revenue-neutral			Reduced direct taxes		
Production Activity	**BENCHMARK Value in Megatons**	**SIM1**	**SIM2**	**SIM3**	**SIM1**	**SIM2**	**SIM3**
Tea and coffee	0.28	0.4	0.4	0.4	0.4	0.4	0.4
Sugar growing (only large-scale)	0.03	-0.8	-0.4	-1.3	-1.1	-0.9	-1.3
Tobacco growing	0.51	0.2	0.2	0.1	0.2	0.2	0.1
Fisheries	0.53	0.0	0.0	0.1	0.2	0.2	0.1
Livestock and poultry	0.18	-0.4	-0.5	-0.1	-0.3	-0.4	-0.2
Mining	7.90	-0.5	-0.8	0.8	-0.4	-0.7	0.6
Meat products	5.23	-0.2	-0.4	0.1	-0.1	-0.2	0.1
Grain milling	6.73	0.0	0.0	0.0	0.0	0.1	0.0
Bakeries and confectioneries	4.10	-1.0	-1.3	0.1	-0.7	-0.9	0.0
Sugar production	0.10	-0.1	-0.1	0.1	0.2	0.2	0.1
Beverages and tobacco	116.68	-1.8	-2.4	0.4	-1.4	-1.8	0.0
Textiles and wearing apparel	2.95	1.0	0.8	1.5	1.2	1.0	1.5
Paper and printing	3.50	-2.7	-1.3	-5.2	-3.7	-2.5	-5.0
Chemicals	2.60	1.5	1.9	1.0	1.3	1.7	1.1
Soaps, detergents and toiletries	148.35	-13.1	-26.4	1.2	-13.4	-26.8	-0.8
Rubber products	2.87	15.1	14.4	17.8	16.0	15.6	17.7
Non-metallic mineral products	16.44	0.5	-0.2	2.5	0.3	-0.4	2.2
Fabricated metal products	3.26	2.5	2.9	1.8	2.2	2.5	1.9
Plant and machinery	3.51	13.7	13.3	14.4	13.7	13.4	14.4
Construction	9.89	-1.8	-1.4	-2.3	-2.4	-2.1	-2.4
Oil distribution	2.95	1.2	1.2	1.2	1.2	1.3	1.2
Agricultural distribution	4.04	1.2	1.3	1.1	1.3	1.4	1.1
Other distribution	0.89	-1.2	-1.2	-1.0	-1.2	-1.2	-1.1
TOTAL	**343.52**	**-6.0**	**-12.0**	**1.5**	**-6.0**	**-12.0**	**1.5**

Table B 14: Changes (%) in aggregate biomass fuel demand

		No revenue neutrality			Reduced direct taxes		
Industry	**Benchmark value in Megaton**	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Agriculture	11.03	0.2	0.2	0.2	0.2	0.2	0.2
Manufacturing	42.46	-2.1	-2.9	0.1	-1.8	-2.4	-0.3

Table B 15: Changes (%) in aggregate hydropower demand

		No revenue neutrality			Reduced direct taxes		
Industry	**Benchmark value in Mega-Btu**	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Mining	11.87	-0.5	-0.8	0.8	-0.4	-0.7	0.6
Agriculture	11.54	0.1	0.1	0.1	0.2	0.2	0.1
Manufacturing	137.20	7.0	6.2	9.4	7.6	6.9	9.1
Services	10.48	0.9	0.9	0.9	0.9	0.9	0.9
Construction	2.53	-1.8	-1.4	-2.3	-2.4	-2.1	-2.4

Table B 16: Changes (%) in sectoral demand for biomass fuel

		No revenue-neutral			Recycled to Direct Tax		
Production Activity	**Benchmark Value in Megatons**	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Tea and coffee	3.12	0.4	0.4	0.4	0.4	0.4	0.4
Sugar growing (only large-scale)	0.41	-0.8	-0.4	-1.3	-1.1	-0.9	-1.3
Tobacco growing	7.50	0.2	0.2	0.1	0.2	0.2	0.1
Sugar production	1.48	-0.1	-0.1	0.1	0.2	0.2	0.1
Beverages and tobacco	37.27	-1.8	-2.4	0.4	-1.4	-1.8	0.0
Paper and printing	2.62	-2.7	-1.3	-5.2	-3.7	-2.5	-5.0
Soaps, detergents and toiletries	1.05	-13.1	-26.4	1.2	-13.4	-26.8	-0.8
Fabricated metal products	0.03	2.5	2.9	1.8	2.2	2.5	1.9
TOTAL	**53.49**	**-1.6**	**-2.2**	**0.1**	**-1.3**	**-1.9**	**-0.2**

Table B 17: Changes (%) in sectoral demand for hydropower in Btu

		No revenue-neutral			Recycled to Direct Tax		
	Benchmark value in Mega-Btu	**SIM 1**	**SIM 2**	**SIM 3**	**SIM 1**	**SIM 2**	**SIM 3**
Tea and coffee	3.19	0.4	0.4	0.4	0.4	0.4	0.4
Sugar growing (only large-scale)	0.29	-0.8	-0.4	-1.3	-1.1	-0.9	-1.3
Tobacco growing	5.25	0.2	0.2	0.1	0.2	0.2	0.1
Fisheries	0.99	0.0	0.0	0.1	0.2	0.2	0.1
Livestock and poultry	1.82	-0.4	-0.5	-0.1	-0.3	-0.4	-0.2
Mining	11.87	-0.5	-0.8	0.8	-0.4	-0.7	0.6
Meat products	1.02	-0.2	-0.4	0.1	-0.1	-0.2	0.1
Grain milling	4.61	0.0	0.0	0.0	0.0	0.1	0.0
Bakeries and confectioneries	1.38	-1.0	-1.3	0.1	-0.7	-0.9	0.0
Sugar production	1.32	-0.1	-0.1	0.1	0.2	0.2	0.1
Beverages and tobacco	35.40	-1.8	-2.4	0.4	-1.4	-1.8	0.0
Textiles and wearing apparel	1.29	1.0	0.8	1.5	1.2	1.0	1.5
Paper and printing	1.42	-2.7	-1.3	-5.2	-3.7	-2.5	-5.0
Chemicals	3.22	1.5	1.9	1.0	1.3	1.7	1.1
Soaps, detergents and toiletries	2.75	-13.1	-26.4	1.2	-13.4	-26.8	-0.8
Rubber products	67.30	15.1	14.4	17.8	16.0	15.6	17.7
Non-metallic mineral products	12.10	0.5	-0.2	2.5	0.3	-0.4	2.2
Fabricated metal products	2.89	2.5	2.9	1.8	2.2	2.5	1.9
Plant and machinery	2.50	13.7	13.3	14.4	13.7	13.4	14.4
Construction	2.53	-1.8	-1.4	-2.3	-2.4	-2.1	-2.4
Oil distribution	0.60	1.2	1.2	1.2	1.2	1.3	1.2
Agricultural distribution	5.21	1.2	1.3	1.1	1.3	1.4	1.1
Other distribution	4.24	0.6	0.6	0.8	0.6	0.6	0.7
Hotels, bars, and restaurants	0.43	-1.2	-1.2	-1.0	-1.2	-1.2	-1.1
TOTAL	**173.61**	5.6	4.9	7.5	6.0	5.5	7.3

Table B 18: Changes in labour intensive and capital intensive sectoral outputs

	Non revenue-neutral					Distributed to households	
Sector	Share of labour in value added	Share of capital in value added	Benchmark output in MKW million	Average output Simulations 1 & 2	% Change in Output	Average output Simulations 1 & 2	% Change in output
Forestry	0.8	0.2	662.2	672.6	1.6	668.8	1.0
Public services	0.8	0.2	6203.8	6126.2	-1.3	6179.8	-0.4
Fisheries	0.8	0.2	335.7	336.5	0.2	340.5	1.4
Non-metallic mineral products	0.8	0.2	503.9	511.6	1.5	502.3	-0.3
Mining	0.8	0.2	707.9	686.5	-3.0	690.8	-2.4
Wood products and furniture	0.7	0.3	1874.9	1944.4	3.7	1951.2	4.1
Hotels, bars, and restaurants	0.7	0.3	2774.6	2630.7	-5.2	2636.8	-5.0
Banking and insurance	0.6	0.4	2461.8	2561.9	4.1	2597.5	5.5
Oil distribution	0.6	0.4	583.8	604.9	3.6	606.4	3.9
Personal and social services	0.6	0.4	2164.0	2087.9	-3.5	2064.8	-4.6
Livestock and poultry	0.6	0.4	1532.3	1482.6	-3.2	1493.8	-2.5
Other distribution	0.6	0.4	8323.4	8501.7	2.1	8514.4	2.3
Other crops	0.6	0.1	9078.6	9098.4	0.2	9130.6	0.6
Agricultural distribution	0.6	0.4	3331.6	3479.9	4.4	3488.5	4.7
Business services	0.6	0.4	1396.3	1171.5	-16.1	1072.4	-23.2
Maize (only small-scale)	0.6	0.0	5095.4	5057.6	-0.7	5052.3	-0.8
Telecom and transportation	0.5	0.5	3417.9	3444.3	0.8	3433.1	0.4
Total output for labour intensive sectors			**50448.1**	**50399.2**	**-0.1**	**50423.7**	**0.0**
Change (overall)				**-48.9**		**-24.4**	
Plant and machinery	0.5	0.5	1173.4	2506.6	113.6	2514.6	114.3
Electricity and water	0.4	0.6	2862.1	2984.8	4.3	2940.9	2.8
Construction	0.4	0.6	3226.3	2975.5	-7.8	2883.8	-10.6
Bakeries and confectioneries	0.4	0.6	423.9	402.9	-5.0	408.9	-3.5
Fabricated metal products	0.4	0.6	1988.5	2272.0	14.3	2233.4	12.3
Textiles and wearing apparel	0.4	0.6	2300.6	2478.9	7.8	2520.7	9.6
Grain milling	0.4	0.6	7625.9	7602.3	-0.3	7686.4	0.8
Sugar production	0.4	0.6	1601.8	1592.4	-0.6	1619.7	1.1
Meat products	0.4	0.6	1653.0	1612.1	-2.5	1639.4	-0.8
Dairy products	0.4	0.6	528.1	534.5	1.2	539.9	2.2
Chemicals	0.3	0.7	2159.1	2500.0	15.8	2456.3	13.8
Tobacco growing	0.3	0.4	8680.4	8817.4	1.6	8828.8	1.7
Tea and coffee	0.3	0.4	2308.6	2427.2	5.1	2429.2	5.2
Sugar growing (only large-scale)	0.2	0.5	260.9	252.9	-3.0	248.0	-4.9
Soaps, detergents and toiletries	0.2	0.8	1741.1	964.0	-44.6	952.5	-45.3
Beverages and tobacco	0.2	0.8	3066.1	2806.9	-8.5	2867.6	-6.5
Paper and printing	0.1	0.9	1858.2	1758.5	-5.4	1705.1	-8.2
Rubber products	0.1	0.9	448.8	643.1	43.3	658.7	46.8
Total output for capital intensive sectors			**43906.6**	**45132.0**	**2.8**	**45133.9**	**2.8**
Change (overall)				**1225.3**		**1227.3**	

Table B 19: Export supply and import demand (%) changes

Sector/Flows		Non revenue-neutral			Distributed to households		
Export Supply:	*Benchmark Values*	*SIM 1*	*SIM 2*	*SIM 3*	*SIM 1*	*SIM 2*	*SIM 3*
Maize (only small-scale)	128.9	1.5	1.5	1.1	-0.7	-1.1	0.6
Tea and coffee	1659.4	5.4	5.2	5.5	5.5	5.4	5.5
Tobacco growing	8579.6	1.6	1.7	0.9	1.7	1.9	1.0
Fisheries	20.5	1.1	0.8	1.7	-0.9	-1.3	1.1
Livestock and poultry	0.4	0.9	0.9	0.4	-1.2	-1.5	0.0
Other crops	2005.5	0.6	0.6	0.0	-1.5	-1.8	-0.3
Grain milling	32.4	1.2	1.1	1.0	-0.5	-0.8	0.6
Sugar production	550.1	0.0	-0.2	0.8	1.2	1.3	0.8
Beverages and tobacco	121.5	-17.2	-22.9	7.5	-17.0	-21.9	1.2
Textiles and wearing apparel	608.2	6.9	5.0	10.1	7.0	5.3	9.7
Wood products and furniture	75.9	11.2	11.6	9.8	11.4	11.9	10.2
Paper and printing	141.7	2.7	3.5	1.5	4.2	5.3	1.8
Chemicals	38.2	11.9	11.8	12.3	13.2	13.3	12.6
Soaps, detergents and toiletries	84.7	-45.8	-64.0	8.0	-47.1	-64.7	-4.2
Rubber products	347.4	9.1	8.5	11.6	10.2	9.9	11.5
Non-metallic mineral products	9.5	2.8	-3.9	26.3	2.3	-3.8	22.2
Fabricated metal products	13.2	14.3	14.8	13.4	15.7	16.5	14.0
Plant and machinery	419.4	28.3	29.3	26.2	29.5	30.8	27.2
Hotels, bars and restaurants	756.1	-0.5	-1.4	1.5	0.5	-0.2	1.2
Telecom and transportation	885.5	3.2	3.6	1.7	4.7	5.4	2.2
Banking and insurance	1224.5	3.1	3.2	1.8	4.5	4.9	2.3
Business services	319.3	1.9	2.1	0.7	3.4	3.8	1.2
Total Exports	***18021.9***	***2.0***	***0.6***	***6.6***	***2.1***	***0.9***	***5.6***
Import Demand:	*Benchmark Values*	*SIM 1*	*SIM 2*	*SIM 3*	*SIM 1*	*SIM 2*	*SIM 3*
Maize (only small-scale)	1774.2	-1.5	-1.5	-1.1	0.7	1.1	-0.6
Tea and coffee	8.4	-5.1	-5.0	-5.3	-5.2	-5.1	-5.2
Fisheries	6.1	-1.1	-0.8	-1.7	0.9	1.3	-1.1
Livestock and poultry	4.3	-0.8	-0.9	-0.4	1.2	1.5	0.0
Other crops	59.3	-0.6	-0.6	0.0	1.6	1.8	0.3
Meat products	696.7	0.7	1.0	-0.5	1.9	2.2	0.0
Dairy products	125.8	-2.7	-3.3	-0.9	-3.5	-4.3	-1.4
Grain milling	471.8	-1.1	-1.1	-1.0	0.5	0.8	-0.6
Bakeries and confectioneries	157.2	5.3	6.7	-0.4	5.4	6.6	0.8
Sugar production	189.2	0.0	0.2	-0.8	-1.2	-1.3	-0.8
Beverages and tobacco	159.5	20.8	29.7	-7.0	20.5	28.0	-1.2
Textiles and wearing apparel	1615.7	-6.4	-4.7	-9.2	-6.6	-5.0	-8.8
Wood and furniture	262.5	-10.1	-10.4	-9.0	-10.2	-10.6	-9.3
Paper and printing	729.8	-2.7	-3.4	-1.5	-4.0	-5.1	-1.8
Chemicals	3597.0	-10.7	-10.5	-10.9	-11.7	-11.8	-11.2
Soaps, detergents and toiletries	275.4	84.4	177.6	-7.4	89.2	183.7	4.4
Rubber products	852.2	-8.4	-7.8	-10.4	-9.2	-9.0	-10.3
Non-metallic mineral products	458.6	-2.7	4.1	-20.8	-2.2	4.0	-18.2
Fabricated metal products	1335.6	-12.5	-12.9	-11.8	-13.6	-14.2	-12.3
Plant and machinery	4671.8	-22.1	-22.7	-20.8	-22.8	-23.5	-21.4
Hotels, bars and restaurants	1712.8	0.5	1.5	-1.5	-0.5	0.2	-1.2
Telecom and transportation	2025.7	-3.1	-3.5	-1.6	-4.5	-5.1	-2.2
Banking and insurance	1695.7	-3.0	-3.1	-1.8	-4.3	-4.7	-2.3
Business services	857.8	-1.9	-2.0	-0.7	-3.3	-3.7	-1.2
Total Imports	**23743.0**	**0.6**	**5.3**	**-5.3**	**0.8**	**5.3**	**-4.4**

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